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The Judges said, "You're lovely,
But the others, too, are neat."
So we'll have to look you over
From your head down to your feet.

Then I heard them talk of "structures"
And of "sweet formations," too.
Why, you'd thought a bunch of oil men
Were discussing leases new.

But the Judges, unlike oil men,
Had no Mayes and Bevan survey
That would aid them in deciding
Who the winner was that day.

August 1947

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Volume 31 Number 8

BULLETIN
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AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

AUGUST, 1947

GEOLOGY OF ROMA DISTRICT, QUEENSLAND, AUSTRALIA[1]

FRANK REEVES[2]
Kensington, Maryland

ABSTRACT

Since the discovery of gas in 1900 in drilling for water at Roma, southeastern Queensland, 40 wells have been drilled in the area. A few of these wells encountered some gas and showings of oil. Most of the wells were drilled in areas where the outcropping Cretaceous and Jurassic strata show no evidence of structure except for a slight southward tilt toward the center of the Great Artesian Basin. Consequently, most of the drilling was a hit-or-miss affair. About all that was known about the subsurface geology was that basement rocks in the vicinity of Roma underlay the surface at depths of 2,000–4,100 feet, and that oil and gas showings were found slightly above the basement rocks in non-marine formations thought to be Jurassic in age.

In 1933 Oil Search Ltd. of Sydney initiated a program of geological work and exploratory drilling in the region. During 1934 and 1935 a large area was mapped north of Roma, and two or three promising structures were outlined. During 1934–1939 Oil Search drilled three deep tests in the area, two of which were located on pronounced anticlines located 60–85 miles north of Roma, the other being a test of a minor structure a few miles east of Roma. Gas was struck in two of the wells, but only slight showings of oil were encountered. The main facts established by the geological investigations and exploratory drilling are as follows.

1. Well defined anticlinal folds are present in outcropping Permian strata 80–120 miles north of Roma. Although a slight unconformity exists between the Permian and Triassic, and a marked unconformity occurs at the base of the Upper Triassic, the folds in the Permian can be traced southwest in the mild folds of the Triassic, but disappear in the gently southerly tilt of the Jurassic strata.

2. The combined thickness of the Jurassic and Triassic is only 3,500–5,500 feet, and not 12,000 feet as formerly estimated. The Permian strata at their outcrop are only 5,100–7,000 feet thick, or about half as thick as previously reported.

3. The principal oil and gas showings at Roma were found in sandstones and grits of Triassic, not Jurassic age.

[1] Manuscript received, April 20, 1947.

[2] Consulting geologist. The writer was ably assisted in the field work by W. A. Findlay, W. P. Wilson, A. W. Atkinson, and E. M. Braes, and had the benefit of the expert advice and direction of the company's chief geologist, D. Dale Condit. The Queensland and Commonwealth Geological Surveys co-operated fully in the field investigations. Thanks are due especially to the Queensland Survey's chief geologist, L. C. Ball, and to F. W. Whitehouse, Queensland paleontologist, and to Irene Crespin, Commonwealth paleontologist. The writer wishes to acknowledge also his indebtedness to the officials of Oil Search Ltd., under whose aegis the investigation was carried out. Credit for the company's policy of backing adequate geological work and allowing the results to be published is due largely to the late E. L. Walter. Lastly, the writer wishes to express his thanks to H. G. Raggatt, director, Australian Bureau of Mineral Resources, Geology and Geophysics, for his cooperation in the publication of this paper.

4. None of the forty wells drilled in the region, except Oil Search's Hutton and Arcadia tests, was located on an appreciable fold. All earlier wells, except the one at Wallumbilla, were situated on a southeasterly trending basement ridge, the crest of which is transgressed by Triassic strata.

5. The gas encountered in the Triassic near Roma and in the Permian at Arcadia probably originates from Permian carbonaceous strata. The oil encountered at Roma may have had its source in the few hundred feet of marine strata that occur in the middle and lower Bowen series of Permian age. All other strata below the thin mantle of Cretaceous in the vicinity of Roma are non-marine in origin.

Introduction

GENERAL STATEMENT

Intermittent drilling has been carried on in the search for oil and gas in the vicinity of Roma, Queensland, during the past 47 years. Because of the scarcity and unreliability of bed-rock exposures, most of the drilling was done more or less blindly, although some of the operating companies made considerable effort to acquire expert geological advice. No thorough exploratory work, however, had been done in the region until Oil Search Ltd. of Sydney began its field investigations in 1934. Upon the advice of its chief geologist, it initiated a program of regional mapping to obtain information on which to base exploratory drilling. The writer was employed by Oil Search from July, 1944, to July, 1946, to carry out this program. The present paper summarizes the main results of this investigation and the data obtained in the wells drilled.

GEOGRAPHY

Location and culture.—The area under consideration occupies the northeastern margin of the Great Artesian Basin in southeastern Queensland (Fig. 1). It covers a strip of country 30–50 miles wide, extending 130 miles northward from Roma (Fig. 2). Roma, a town of about 4,000 inhabitants, is at the southern margin of the area. For a distance of 60 miles north of Roma the country is occupied by small dairy and fruit farms. In the rugged country farther north, there are a few large cattle stations.

Most of the land, except where cleared for farming, is covered by a thick growth of eucalyptus trees and scrub.

Topography and drainage.—Peaks, mesas, and tablelands capped by basalt in the northwestern part of the area rise to 3,000–3,200 feet above sea-level. The Carnarvon and Expedition ranges consist of northerly and westerly facing sandstone escarpments having elevations of 2,000–3,000 feet. These escarpments, together with their re-entrant canyons, form a very rugged country. North of the Carnarvon Range are extensive lowland flats at elevations of less than 1,000 feet. South of the Carnarvon Range the country has a gradual southerly slope except for the occurrence of stream valleys and low sandstone ridges. At Injune the surface has a general elevation of 1,250 feet, and at Roma 1,000 feet.

The so-called Great Dividing Range runs southward along the western border of the area to a point 25 miles southwest of Injune, and thence in a general southeastwardly direction. In the north this range rises to elevations of more than

3,000 feet, but subsides in a short distance southward. North of Roma it has a maximum elevation of approximately 1,500 feet and is not a recognizable feature of the landscape—merely a stream divide.

The draining of the area south and west of the Great Dividing Range is southward into the tributaries of the Murray River, which flows into the Southern Ocean. North and east of the divide the drainage is into the Dawson and Comet rivers, tributaries of the McKenzie, which flows into the Fitzroy. The Fitzroy

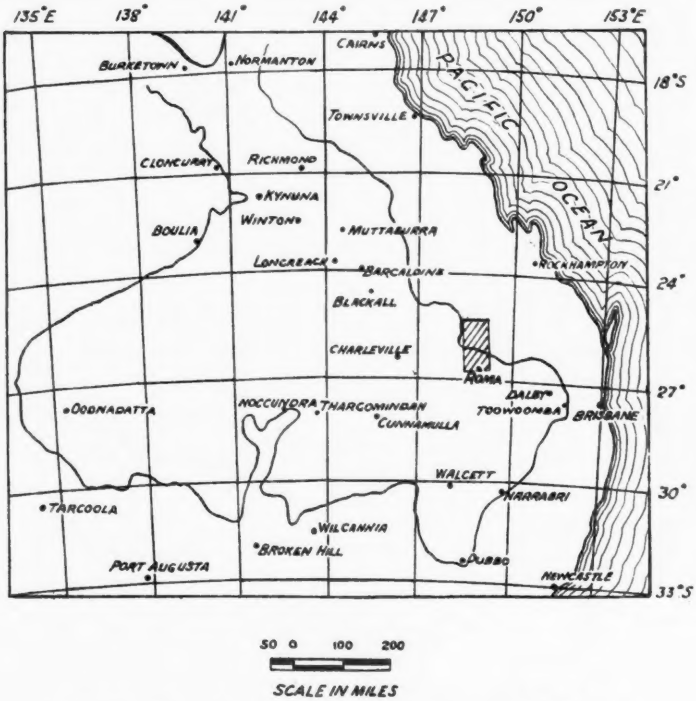
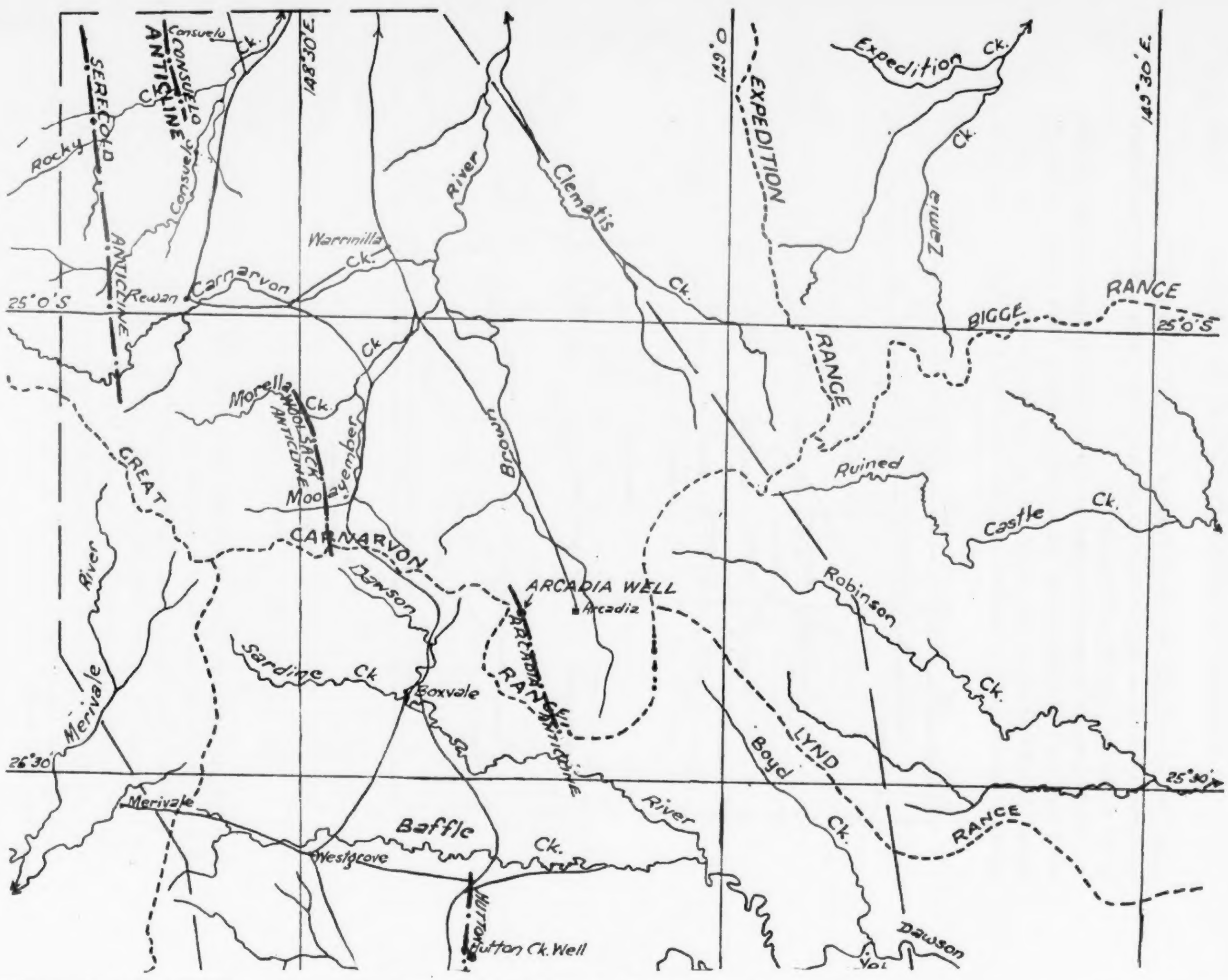


FIG. 1.—Index map, showing Great Artesian Basin and area of report.

River empties into the Pacific Ocean near Rockhampton. Very few of the streams of the area flow except during the summer rainy season.

Climate.—The mean annual temperature at Roma is 68.5°F. The annual rainfall is irregular in volume, but averages 23–25 inches. Most of it comes in the summer months with torrential downpours. During the remainder of the year there is very little precipitation. With the exception of the late spring and summer months, when the thermometer rises to 100–105°F. in the shade, the weather is ideal for field work.



148°30'E.
149°0
149°30'E.
25°0'S
25°30'
26°30'
EXPEDITION RANGE
BIGGE RANGE
CARNARVON GREAT RANGE
LYND RANGE
ARCADIA RANGE ANTICLINE
ARCADIA WELL
Arcadia
CONSUELO ANTICLINE
SERFCOLD ANTICLINE
WOOLSACK ANTICLINE
HUTTON
Hutton Ck. Well
Expedition Ck.
Zamia Ck.
Clematis Ck.
Brown River
Warrinilla Ck.
Carnarvon Ck.
Rewan
Consuelo Ck.
Consuelo
Rocky
Morella Ck.
Moolayember
Ruined
Castle Ck.
Robinson Ck.
Boyd Ck.
Dawson River
Dawson
Sardine Ck.
Boxvale
Baffle Ck.
Westgrove
Merivale River
Merivale

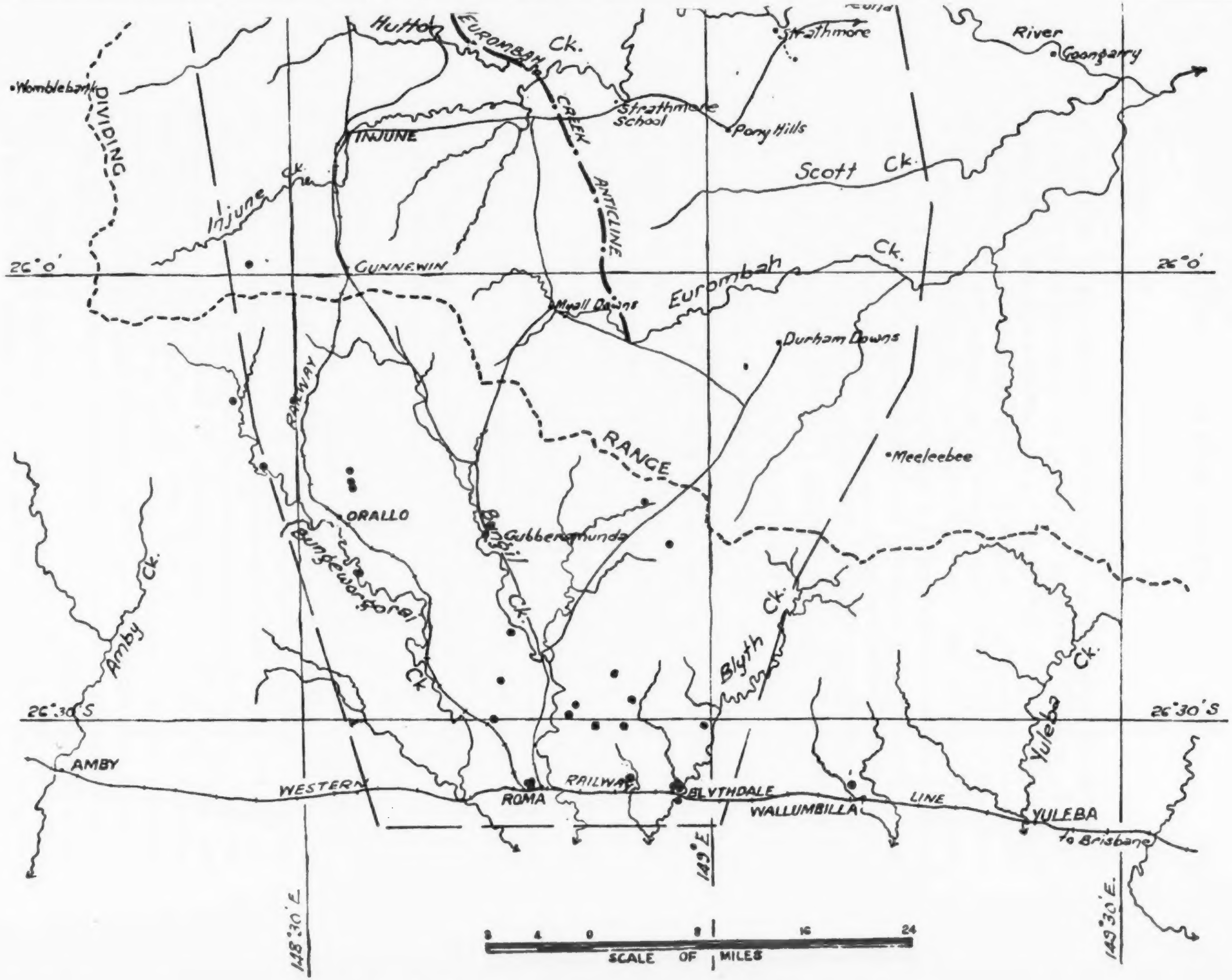


FIG. 2.—Map showing geographic features, axes of folds and other data.

Surface Geology

STRATIGRAPHIC SECTION

General statement.—The area under review lies chiefly within the Great Artesian Basin, which is surfaced by Cretaceous strata overlying Jurassic and Triassic formations. The latter formations crop out north of Roma. Farther north, Permian strata appear at the surface (Pl. 1). Remnants of Tertiary basaltic flows overlie strata ranging in age from Cretaceous to Permian. The oldest strata exposed are the Dilly shales (lower Bowen) which crop out in the crest of the Serocold anticline 125 miles north of Roma. No older formations are penetrated in the wells except in the vicinity of Roma where granite and metamorphic rocks are encountered in several wells. The total thickness of the exposed sedimentary strata is approximately 11,000 feet divided as follows: Cretaceous 200 feet, Jurassic 2,550 feet, Triassic 1,000–3,000 feet, Permian 5,100–7,000 feet (Table I).

MESOZOIC FORMATIONS

Cretaceous.—Cretaceous strata consisting chiefly of dark marine clay shales occupy a belt of black soil in the vicinity of Roma. Only the basal 200 feet of the Cretaceous is present in the area north of Roma. Whitehouse (1930) has correlated these shales with the Aptian on the basis of a considerable marine fauna.

Jurassic.—Below the Cretaceous shales is a series of non-marine slightly indurated sandstones, sandy clay shales and coal beds, which on the basis of plant fossils and dinosaur remains Jensen (1926) has identified as Jurassic in age. The lithologic units recognized by the Queensland Geological Survey were adopted in mapping the Jurassic, except that the basal Walloon sandstone is here included with the Triassic (Table I). The exact boundary between the Jurassic and Triassic, however, has not been definitely determined.

The thickness of the Jurassic was formerly estimated at 5,000 feet, but the field work done by Oil Search Ltd. showed that it is approximately 2,550 feet thick.

TRIASSIC

Bundamba series.—Underlying the Jurassic is a sandstone series 1,000–1,500 feet thick, which Queensland geologists have called the Bundamba and classified as Upper Triassic in age. We have divided the series into three members—the Hutton, Boxvale, and Bundamba sandstones. They are persistent lithologic units and were used as horizon-markers in mapping the gentle folds in the area of Triassic outcrops. The Hutton sandstone forms the sandy soils that cover extensive areas on Westgrove Station. It varies markedly in thickness, being 400 feet thick south of Injune and 1,000 feet thick in the vicinity of Pony Hills east of Injune.

The Boxvale sandstone is 30–80 feet thick and forms prominent cliffs and a network of re-entrant canyons along the principal streams northwest and southeast of Boxvale Station.

The Bundamba sandstone is 200–250 feet thick and forms the high rim-rocks and precipitous cliffs of the Carnarvon Range. An angular quartz pebble bed

TABLE I

EXPOSED ROCKS

Geologic Age	*Series (Thickness in Feet)*	*Stage or Member (Thickness in Feet)*	*Character*
Quaternary and Recent		Alluvium 10–50	Sand and gravel
Tertiary		Volcanic rocks	Basaltic flows, rhyolites, *et cetera*
Lower Cretaceous	Roma	Rolling Downs formation 200+	Dark gray marine shale, lenses of siliceous limestone, with friable porous sandstones at base
Jurassic 2,500	Upper Walloon 800	Transition stage 550–600	Soft arkosic sandstone, gray sandy clay shale, and lenses of coal
		Mooga sandstone 150-200	Fine to medium-grained sandstone and sandy shale with quartz pebble conglomerate near base
	Middle Walloon 400	Fossil Wood stage 200–300	Sandy clay shale, fine-grained arkosic sandstone with lenses of coal and fossil wood
		Gubberamunda sandstone 200	Medium-grained water-bearing sandstone
	Lower Walloon 1,350	Lower Walloon Coal Measures 1,350	Clay, shale, arkosic sandstone, with minable coal beds near Injune
Triassic 1,000–3,000: Upper Triassic	Bundamba 1000–1500	Hutton sandstone 400–1,000	Arkosic, massive, cross-bedded, coarse-grained to conglomeratic sandstone and sandy clay shale
		Boxvale sandstone 30–80	Thinly bedded, fine-grained cliff-forming sandstone
		Shale 200–250	Chiefly clay shale
		Bundamba sandstone 230–300	Massive to cross-bedded, coarse-grained, conglomerate sandstone. Forms high cliffs in Carnarvon Range
	—Unconformity—		
Middle Triassic	Ipswich 0–1,000	Moolayember shale 0–1,0000	Olive-green, sandy, tuffaceous shale, and thin calcareous sandstone
Lower Triassic	Clematis	Carnarvon sandstone 300–400	Fine-grained, thin- to cross-bedded sandstone with angular quartz pebbles. Forms high red cliffs
	—Unconformity—		
Permian 5,100–7,000	Upper Bowen 1,300–3,200	Variegated clay shale 900–2,800	Red, green, and purple clay shale overlying coarse-grained arkosic sandstone with green pebbles
		Coal Measures 400	Hard greenish arkosic calcareous sandstone with beds of coal and fossil wood in basal part
	Middle Bowen 1,200	Consuelo stage 1,200	Dark gray shale, overlying fossiliferous sandy limestone bed containing several species of marine fossils. This marine horizon overlies 500–600 feet of micaceous clay shale with ridge-forming sandstone at its base
	Lower Bowen 2,600	Ingleara stage 600	Dark sandy marine shale with thin beds of fossiliferous limestone and a glacial boulder bed
		Serocold sandstone 1,700	Massive coarse-grained and conglomeratic sandstone with glacial horizon at top. Forms high ridge on flanks of Serocold anticline
		Dilly stage 300 exposed	Gypsiferous, marine, fossiliferous shale. Glacial horizon at top

ordinarily occupies the base of the sandstone and rests unconformably on underlying strata. As will be shown later, this unconformity is pronounced over anticlinal folds.

Moolayember shale.—In synclinal areas a series of olive-green sandy tuffaceous shale underlies the Bundamba sandstone. Where not removed by pre-Bundamba erosion, the topmost beds consist of light gray shale commonly capped by a band

- QUARTZ
  - Euhedral
  - Subhedral
    - Loose
    - Drusy
    - Granulated
      - Fine
        - Unmodified
        - Lacy
        - Drusy
        - Dolomoldic
          - Skeletal
          - Abundant
          - Scattered
        - Dolomorphic
        - Oolitic
          - Concentric
          - Radiate
          - Sand-centered
          - Massive
          - Clustered
          - Free
          - Drusy
        - Oomoldic
          - Skeletal
          - Abundant
          - Scattered
      - Coarse
        - Unmodified
        - Lacy
        - Drusy
        - Dolomoldic
          - Skeletal
          - Abundant
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        - Dolomorphic
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          - Abundant
          - Scattered
        - Dolomorphic
        - Oolitic
          - Concentric
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          - Massive
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          - Scattered
      - Unmodified
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- SMOOTH
  - Chalcedonic
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- Unmodified
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  - Pseudoolitic
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- Sandy
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- Fossiliferous

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      - Unmodified
      - Lacy
      - Dolomoldic
        - Skeletal
        - Abundant
        - Scattered
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  - SHALE
    - Smooth
      - Flaky
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      - Skeletal
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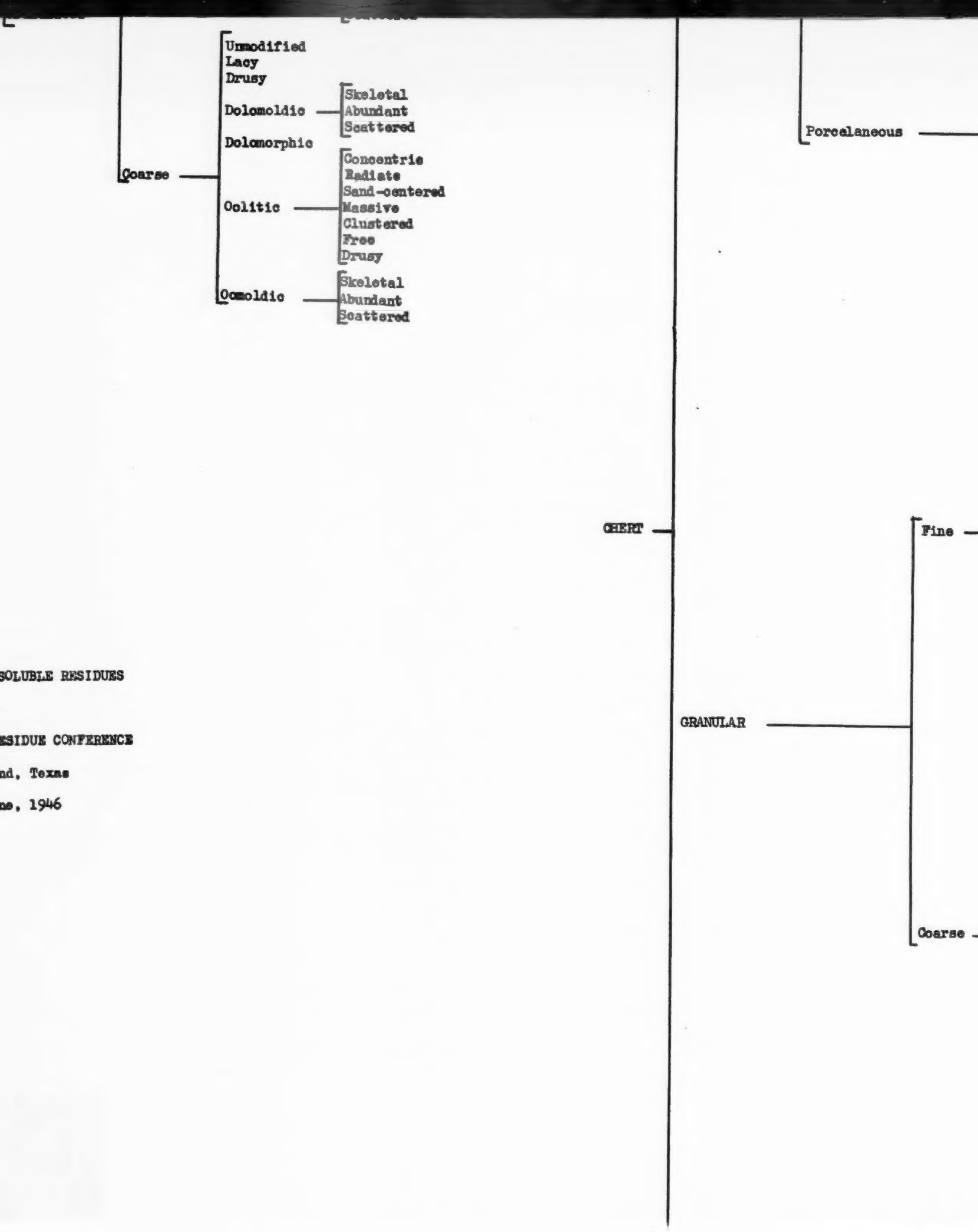

CHART OF INSOLUBLE RESIDUES

by

INSOLUBLE RESIDUE CONFERENCE

Midland, Texas

June, 1946

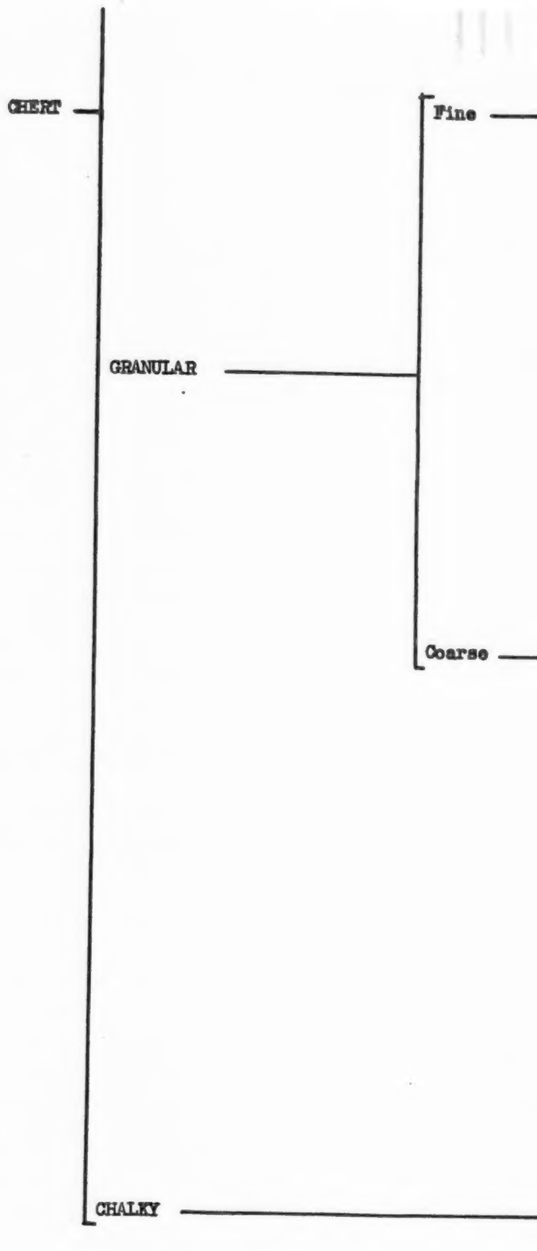

CHART OF INSOLUBLE RESIDUES

by

INSOLUBLE RESIDUE CONFERENCE

Midland, Texas

June, 1946

- Dolomoldic
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  - Abundant
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- Dolomorphic
- Oolitic
  - Concentric
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  - Massive
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  - Pseudoolitic
- Granulated
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- Spicular
- Fossiliferous

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- Sandy
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- Pyritic
- Micaceous
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- ARENACEOUS MATERIAL
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      - Pyritic
      - Micaceous
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    - Aggregates
      - Poorly consolidated
        - Sandy
        - Quartzose
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        - Pyritic
        - Micaceous
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        - Unmodified
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          - Scattered
        - Oolitic
          - Concentric
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          - Massive
        - Oomoldic
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        - Sandy
        - Fossiliferous
        - Glauconitic
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        - Micaceous
        - Other minerals
  - SAND
    - Loose
      - Rounded
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      - Anhedral
  - FIBROUS

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- Fossiliferous

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    - Pyritic
    - Micaceous
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        - Regenerated
      - Well consolidated
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        - Subrounded
          - Frosted
          - Polished
          - Etched
        - Angular
        - Regenerated

- ANHYDRITE
  - MASSIVE
    - Fine granular
    - Coarse aggregates
      - Subhedral
      - Anhedral
  - FIBROUS
  - SUBHEDRAL
  - ANHEDRAL
- GYPSUM
  - MASSIVE
  - FIBROUS
  - SELENITIC

ACCESSORY — Sulphur, pyrite, marcasite, sphalerite, millerite, magnetite, hematite, limonite, feldspar, muscovite, biotite, chlorite, glauconite, barite, celestite, other insoluble minerals; fossils, pellets, beekite.

of red shale ½–1 foot thick, on which rest the coarse grits and conglomerate of the Bundamba sandstone. Reid (1930) regarded this contact as the boundary between the Permian and Triassic. Jensen (1926), however, on the basis of plant fossils, correlated the underlying shale with the Ipswich series of Middle Triassic age. Fossil plants collected by the writer and his assistants from these shales were reported by F. W. Whitehouse to be Triassic in age. A maximum thickness of 1,000 feet was noted along Moolayember Creek. Similar beds are also present on the west flanks of the Serocold and Arcadia anticlines.

Carnarvon sandstone.—A fine-grained arkosic sandstone 300–400 feet thick forms high red cliffs bordering the broad flats north of the Carnarvon Range. At the south end of the Serocold anticline and the southeast side of Arcadia basin, this sandstone is directly overlain by the Bundamba sandstone, the two uniting to form cliffs 400–500 feet high. Reid (1929), in mapping the geology of the area, called this sandstone the Carnarvon, and included it with the Permian. A. K. Denmead, a member of Reid's party, in running a traverse eastward from the Carnarvon sandstone exposures north of Rewan to Clematis Gorge, concluded that the Carnarvon sandstone was older than the sandstone forming Clematis Gorge, which had been identified earlier as Lower Triassic. Actually, the Carnarvon and the sandstone forming the Clematis Creek gorge are the same sandstone. Plant fossils collected by the writer at the base of the Carnarvon sandstone at the Arcadia "Get Down" west of the Arcadia test well were reported by F. W. Whitehouse to be Triassic in age.

MESOZOIC WATER-BEARING SANDSTONES

Most of the flowing wells in the Great Artesian Basin obtain their water from Mesozoic sandstones, which are probably the same sandstones that crop out north of Roma. The more important of these acquifers are probably the Mooga and Gubberamunda sandstones of Jurassic age and the three Triassic sandstone members of the Bundamba series. The Mooga and Gubberamunda sandstones yield large artesian flows in the water bores near Roma. The Bundamba sandstone members are commonly logged in the Roma wells as the "Big sandstone" and reported to be water-bearing. In the area north of Roma these Triassic sandstones are important aquifers. The Hutton sandstone, for example, is the source of the water obtained in several bores near Injune. The Boxvale sandstone yields the sub-artesian flows obtained in several bores on Westgrove, Timor, and adjacent stations. These sandstones, together with the Bundamba and Carnarvon, are the source of most of the permanent springs and water holes in the area of Triassic outcrops. The Boxvale and Bundamba can probably be relied upon to yield artesian water over a wide area east of Arcadia basin which lies outside of the Great Artesian Basin as generally outlined.

The manner in which these Mesozoic sandstones crop out makes it possible for a considerable amount of surface water to be fed into them. All of them, excepting possibly the Carnarvon, occupy long dip slopes lying at 1,000–2,000

feet above the surface of the Artesian Basin. In most of the areas of outcrop the sandstones weather into a loose sandy soil from which there is comparatively little run-off excepting in the heaviest of downpours. The rainfall sinking into these sandy soils is not later evaporated to any extent, and most of it finds its way into the underlying sandstone to supply the artesian flows where the sandstones are penetrated in wells in the Great Artesian Basin. Possibly more of the rainfall in the area of these outcrops could be supplied to these sandstones by impounding streams and diverting their flows across these sandy soil slopes.

PERMIAN FORMATIONS

Permian strata are exposed in the area north of the Carnarvon Range. They have a thickness of 5,100–7,000 feet and consist chiefly of sandy shales with two massive ridge-forming sandstones, and a coal-bearing series. Marine stages occur in the lower part of the section, two of which contain glacial pebbles. In his investigations of the geology of the Serocold anticline, Reid (1929) subdivided the Permian into the upper, middle, and lower Bowen series, and these into several stages (Table I). We adopted his subdivisions in mapping the area, excepting as previously noted we included the Carnarvon sandstone and overlying shale with the Triassic. We also differ with his interpretation of the geology at the north end of the Serocold anticline. He shows an east-west fault with an upthrow on the north of about 3,000 feet, crossing the axis of the anticline, where we show a slight saddle. The sandstone and shale units cropping out on the upthrown side of this predicated fault Reid named the Catherine sandstone, Coral stage, Aldebaran sandstone, and Gypseous stage. These were thought to underlie the Dilly stage—the lowest member exposed on the south side of the fault. We found no evidence of this fault and have concluded that the Catherine sandstone, Coral stage, Aldebaran sandstone, and Gypseous stage are respectively the Consuelo sandstone, Ingleara stage, Serocold sandstone, and Dilly shale. K. Washington Gray visited the district later and concurs with the foregoing interpretation of the geology of the area (Raggatt, 1937).

We found no evidence of marked unconformities in the Permian, but minor ones may be present. An unconformity occurs at the top of the Permian, as is evident by the variation in the interval between the base of the Carnarvon sandstone and the top of the middle Bowen. On the east flank of the Serocold anticline this interval is 3,240 feet. On the west flank it is 1,000 feet less in thickness (Fig. 3). At Cracow, east of the area mapped, there is a well marked unconformity between the Permian and Triassic.

STRUCTURE

GENERAL STATEMENT

The Permian formations in the area mapped show four anticlines, two of which persist southward beneath the transgressive Triassic strata, appearing there as gently arched plunging anticlines. Southeast of these folds a fairly well

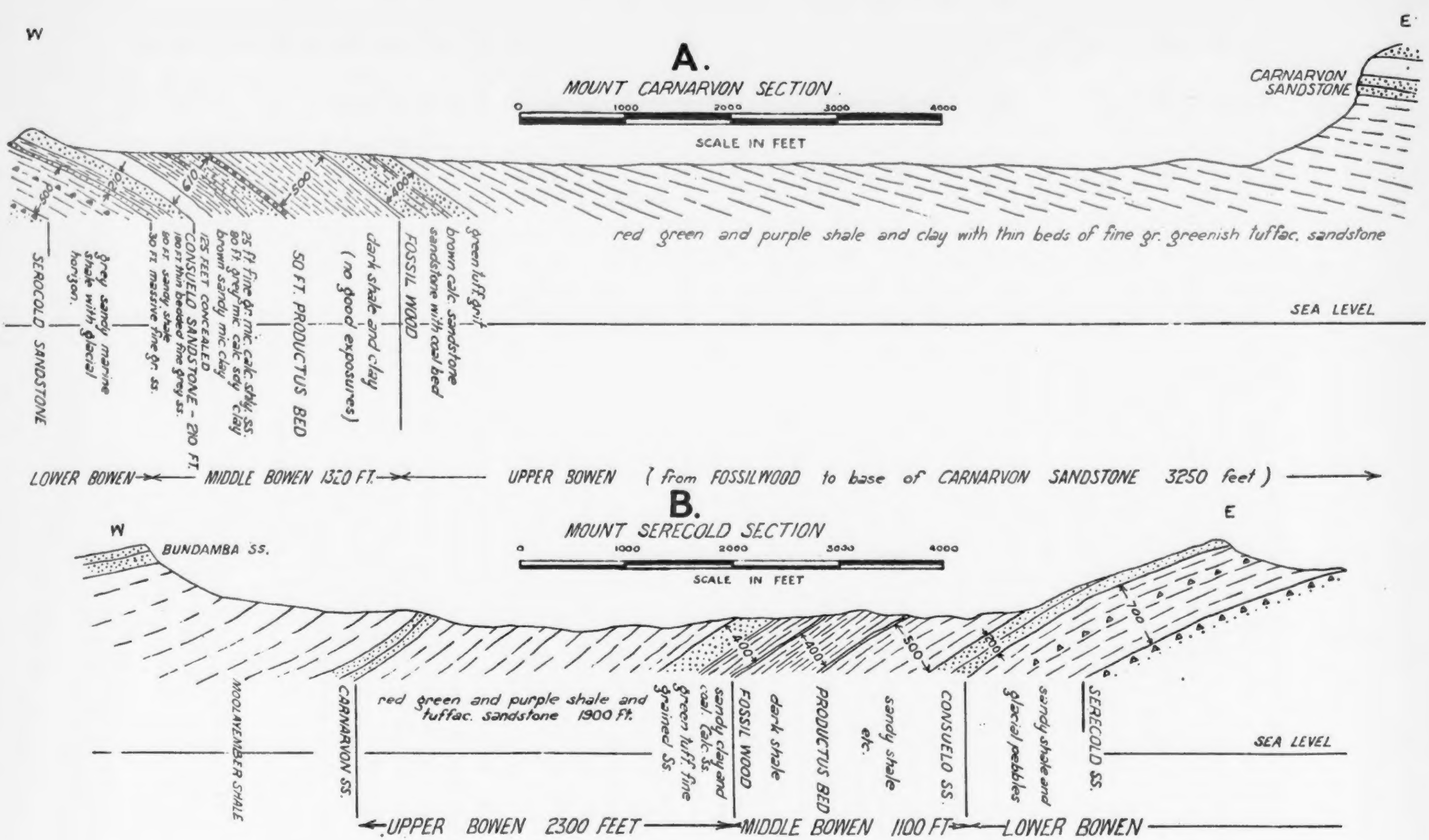

FIG. 3.—Permian formations exposed on flanks of Serocold anticline. A. Mount Carnarvon section. B. Mount Serocold section.

marked anticline has been mapped entirely within the area of Triassic outcrops. No appreciable folds were noted in the Jurassic. The structures of the Permian folds are shown in part by contours and in part by formational boundaries (Pl. 1). Folding in the Triassic is outlined chiefly by contours on the Boxvale and Hutton sandstones.

PERMIAN FOLDS

Serocold anticline.—The Serocold anticline lies at the south end of a major fold that extends north of the area shown in Plate 1. The Serocold anticline has a length of 30 miles, a width of 6–8 miles and a structural relief of 8,000–10,000 feet. In cross section the fold is a broad, slightly asymmetric arch with maximum dips of 40° on its west flank and 25° on its east flank (Fig. 4). No faulting was observed in the area. The Dilly marine stage, the lowest member exposed, occupies a basin surrounded by ridges formed by the Serocold sandstone. Along the axis of the fold extending north of the Serocold anticline, the Aldebaran sandstone forms the crest of the anticline in one locality. This sandstone is about 950 feet thick and evidently directly underlies the Dilly stage. A well drilled on the crest of the Serocold anticline would encounter this sandstone at a shallow depth, below which a thick series of volcanic rocks would probably be penetrated.

The Serocold anticline plunges southward beneath the Triassic, the Bundamba and the Carnarvon sandstones, uniting to form cliffs 400 feet high. Although the unconformity at the base of the Bundamba sandstone is fairly well marked (Fig. 5-A), this Upper Triassic sandstone also shows appreciable arching across the axis of the fold, so that the fold persists as a slightly plunging anticline for a distance of 12 miles south of the Permian exposures.

Consuelo anticline.—This fold lies a few miles northeast of the Serocold anticline from which it is separated by a sharp syncline. Only the south end of the fold appears beneath the basalt cover. In the limited area its of exposure, the middle Bowen is the lowest formation exposed.

Woolsack anticline.—Ten miles east of the south end of the Serocold anticline the upper Bowen formation is exposed on the crest of a small fold. The overlying Carnarvon sandstone shows dips of 15–35° on the east flank of the fold, and 5° on its west flank (Fig. 5-B). The anticline plunges southward beneath the overlapping Bundamba sandstone, which shows a slight plunging fold for a few miles. Due to the lack of exposures the northern extent of this fold is not known, but it probably ends a short distance southeast of Rewan.

Arcadia anticline.—The broad topographic basin east of the Vesta syncline and extending southward to Arcadia station and beyond may have a broad, gentle anticlinal structure. There are few exposures in the basin, but it is evidently floored by the upper Bowen formation. The rim-rock on the east and west sides of the basin is formed by the Carnarvon sandstone, showing slight dips away from the basin. At the south end of the basin the Bundamba sandstone sharply transgresses the Carnarvon sandstone (Fig. 5-C). A few miles west of

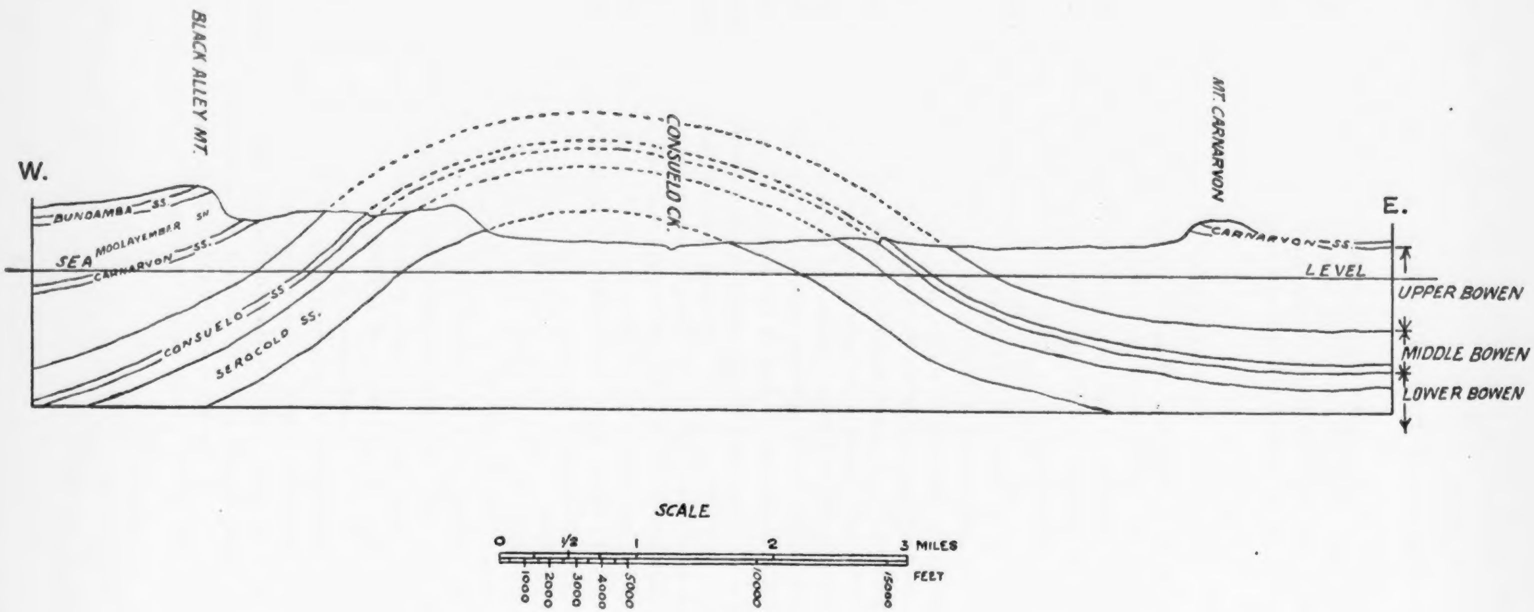

FIG. 4.—Cross section of Serocold anticline.

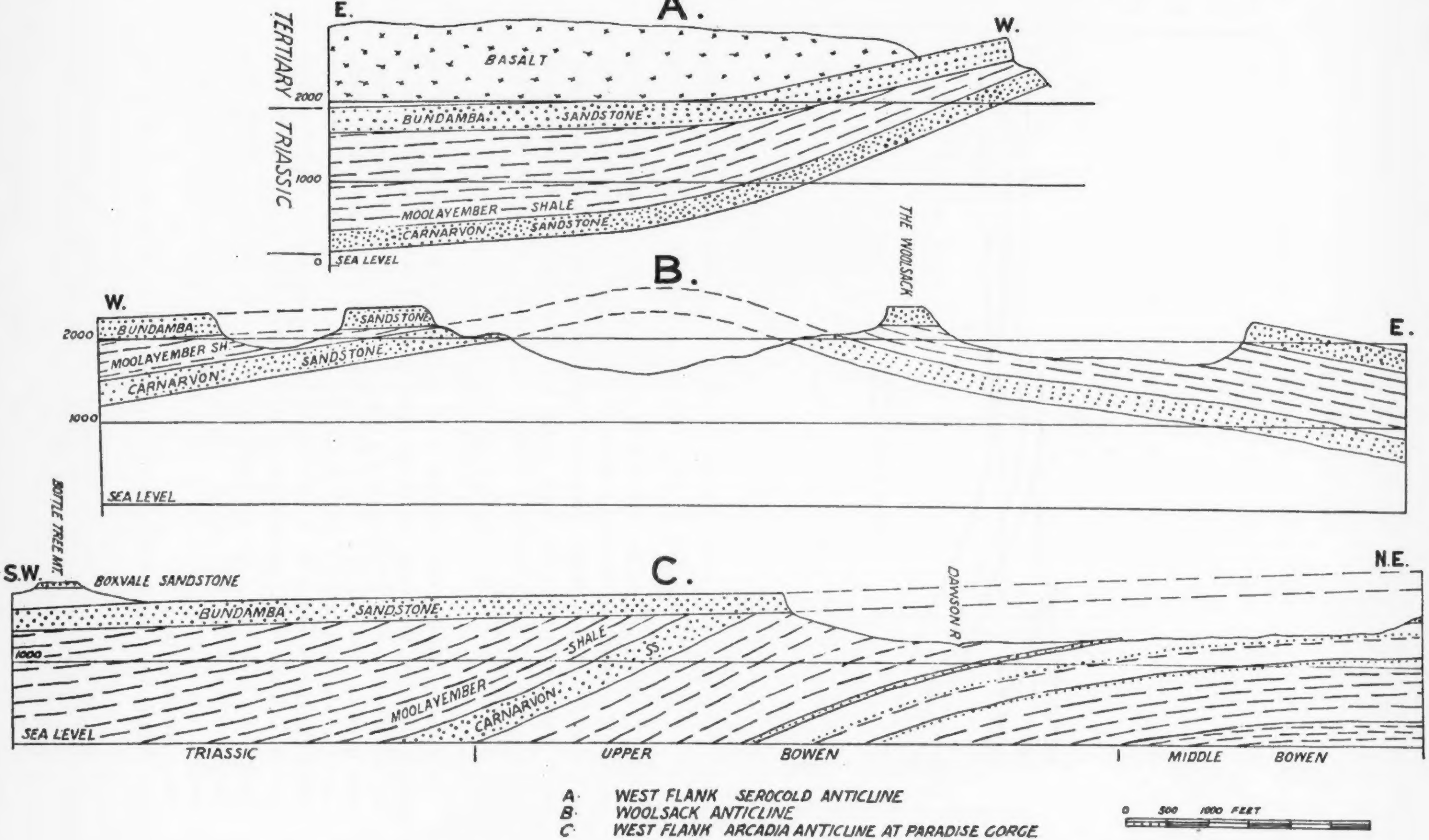

FIG. 5.—Cross section showing unconformity at base of Bundamba sandstone. A. West flank Serocold anticline. B. Woolsack anticline. C. West flank Arcadia anticline at Paradise Gorge.

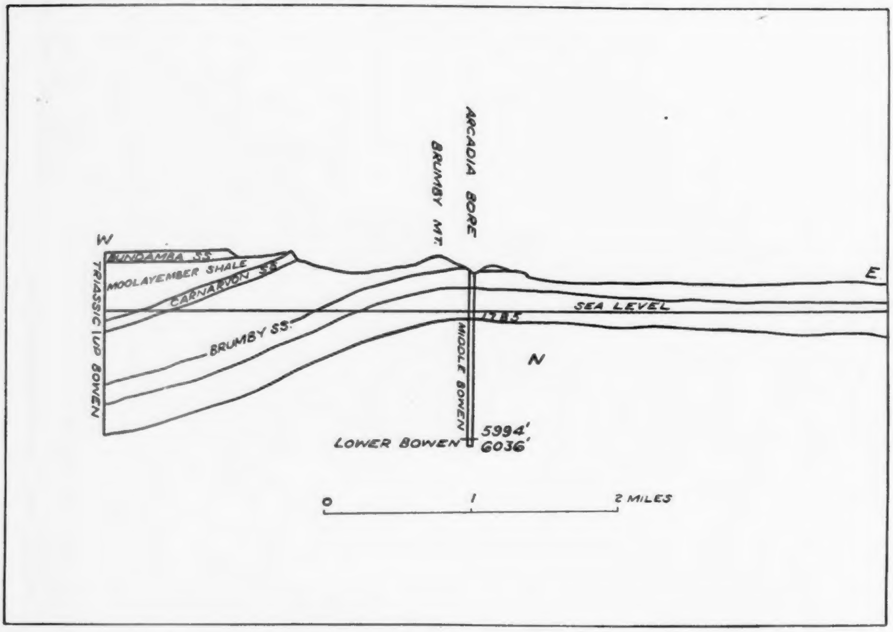

FIG. 6.—Cross section of Arcadia anticline.

Arcadia Station and near the west side of the basin a dome 9 miles long and 4 miles wide was outlined, showing a closure of 700–800 feet. The structure is based on elevations on thin pebble grits and arkosic sandstones in the outcropping upper Bowen formation. The strata on the west flank of the dome show dips of 15–25° and 2–3° on the east flank (Fig. 6). Normal faults of 20–40 feet throw cross the axis of the fold.

TRIASSIC FOLDS

Hutton-Eurombah Creek anticline.—As already noted, Triassic strata are mildly folded at the south end of the Serocold and Woolsack anticlines. The Triassic also shows mild folding along a curving anticlinal axis that extends from near Evergreen to the head waters of Eurombah Creek. Contours on the Boxvale sandstone show the presence of an asymmetric dome at the north end of the anticline. This dome—called the Hutton dome—is 16 miles long and 2–4 miles wide, and has a closure of 200–300 feet. The strata dip eastward at about 2° on the east flank of the fold (Fig. 7). On the west flank, the Boxvale sandstone shows westward dips of 5–13° across a narrow belt, beyond which there are no reliable exposures. The structure of the bordering syncline is based on meager and somewhat unreliable data.

Slight indications of faulting in the nature of calcite veining was observed in

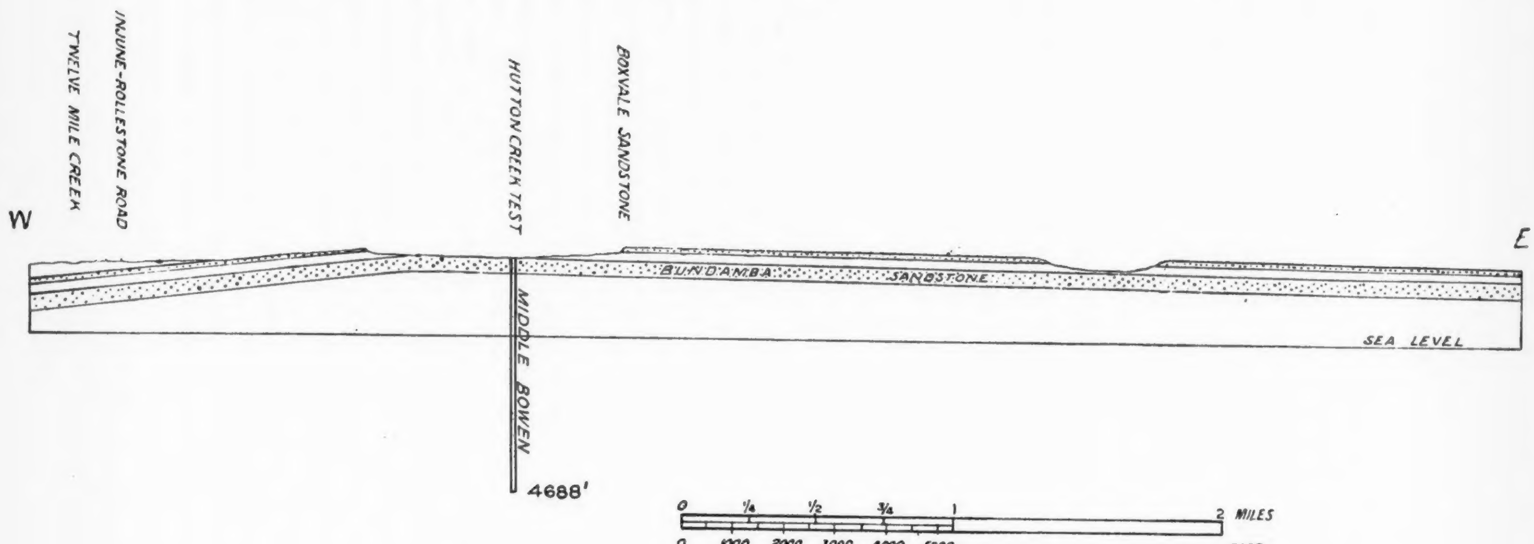

FIG. 7.—Cross section of Hutton dome.

the Boxvale sandstone on the west flank of the anticline, and it is possible that this limb of the fold is broken by a small strike fault.

South of the Hutton dome the axis of folding curves sharply southeast for 8 miles, and thence in a southerly direction for 16 miles. Two minor domes with closures of 100 feet were outlined along the axis of the anticline, but the ledges of the Hutton sandstone on which the contours are based are not very reliable markers for the detailed delineation of such mild folds. A plunging anticline, however, is definitely indicated in the Triassic, and it is likely that a much more pronounced fold exists in the Permian.

JURASSIC STRUCTURES

In the area occupied by Jurassic formations there are no key beds that can be used for detailed structural mapping. The evidence furnished by the mapping of the various stages of the Jurassic, however, indicates that the characteristic structure of the area is that of gently southerly inclined strata. At Gubberamunda a small dome occurs around a small igneous mass which may have a laccolithic form.

AGE OF FOLDING

The exposed Permian strata are at the south end of the Dawson-Bowen sedimentary basin which is 400 miles long and 80–100 miles wide. The northeastern part of this basin is reported by Reid (1929) to be occupied by 18,000 feet of Permian formations. These formations were involved in what David calls the epi-Permian folding, the sediments on the eastern margin of the basin being sharply folded and thrust-faulted during the late Permian by forces acting from the direction of the Pacific. This crustal deformation, according to David, was accompanied or immediately succeeded by widespread intrusions of granite and basic magmas, the eastern margin of the basin being intruded by great and small masses of granite and a multiplicity of basic and andesitic dikes. Westward from this marginal belt of highly disturbed strata the folding decreases in intensity and attains the character of the broad open folds already described. The fact that these westerly folds are asymmetric with steeper dips on their western flank and closely parallel the trend of the folds in the eastern margin of the basin suggests that they are the product of the tangential force that gave rise to the folds in the eastern part of the basin. It is evident, however, that the folding persisted well into the Triassic in the western part of the area. It apparently reached its culmination at progressively later periods from east to west. At Cracow, 100 miles east of Arcadia, the deformation came to an end at the close of the Permian, as indicated by the presence of the Carnarvon sandstone overlapping highly tilted Permian rocks. In the Arcadia basin the folding reached its culmination somewhat later, as is shown by the steep dips of the Carnarvon sandstone overlapped by the Bundamba sandstone (Fig. 5-C). The folding in the Serocold anticline persisted until after the deposition of the Bundamba sandstone, as is indicated by the marked tilting of that member (Fig. 5-A).

Subsurface Geology

SUMMARY OF EXPLORATORY DRILLING

From 1900 to 1934, thirty-four wells were drilled in the search for oil and gas in the vicinity of Roma (Pl. I.) During the next 6 years two deep test wells were drilled in the Carnarvon Range north of Roma, and four a few miles northeast of Roma. The first flow of gas was encountered, 1900, at 3,683 feet in deepening the Government's No. 2 water bore on Hospital Hill at the western edge of Roma (Fig. 8). The gas, estimated at 70,000 cubic feet, flowed into the air for 4 years. A gas plant was then installed and lines were laid to light the streets of Roma, but shortly after the well was shut in the gas ceased to flow. In 1907 the Government completed a second well on Hospital Hill, which had a reported flow of 10,000,000 cubic feet. The gas caught fire, however, and burned for 3 months and then stopped altogether. The Government's third gas well, also on Hospital Hill, was completed in 1920 and had an estimated flow of 22,000,000 cubic feet, with a gasoline content of 1.2 pints per 1,000 cubic feet. A small absorption plant was installed, but the well was soon lost because of the jamming of tools in the hole. A ban was then placed on drilling for oil and gas within a 25-mile radius of Roma.

In 1922, the Lander Oil Field Ltd. was organized, and between 1922 and 1926 drilled three dry holes near Orallo, 25 miles northwest of Roma. In 1926 the ban on drilling was lifted, and during the next 5 years ten companies were organized and about twenty-five wells were drilled. Many of these companies had little capital and no experience in drilling for oil. Among the most active were the Australian Roma Oil Company and the Roma Oil Corporation Ltd., the former drilling ten wells and the latter five. The Roma Oil Corporation's No. 1 on Hospital Hill struck a flow of gas estimated at 600,000 cubic feet. An absorption plant was installed, and about 30,000 gallons of petrol were recovered during the short time it was in operation. Good gas showings were encountered also in other wells, especially those at Blythdale. A little oil was found in the Roma Oil Corporation's No. 2 on Hospital Hill, in the Australian Roma Oil Company's Nos. 4 and 5 at Blythdale, and in the Roma Block No. 1, 7 miles northeast of Roma. Several other wells also reported traces of oil. Flows of water were encountered in most wells in close association with the gas and oil showings.

After 1931 there was a lull in exploratory drilling, only two wells being drilled during 1932 and 1933. Between June, 1933, and September, 1934, Oil Search Ltd. put down 78 shallow scout bores in the vicinity of Roma. The data obtained in these bores and several drilled earlier by Builders Ltd. indicated the presence of a small dome with a closure of 30 feet centering on Warooby Creek, 6½ miles east of Roma. Drillers Ltd., a subsidiary of Oil Search Ltd., drilled a well in 1934 on this dome and encountered a daily flow of 650,000 cubic feet of gas, which was later mudded in awaiting developments. Oil Search Ltd. postponed further drilling until its program of geological mapping was well under way and the structures already described had been mapped. In August and September, 1935, it drilled a

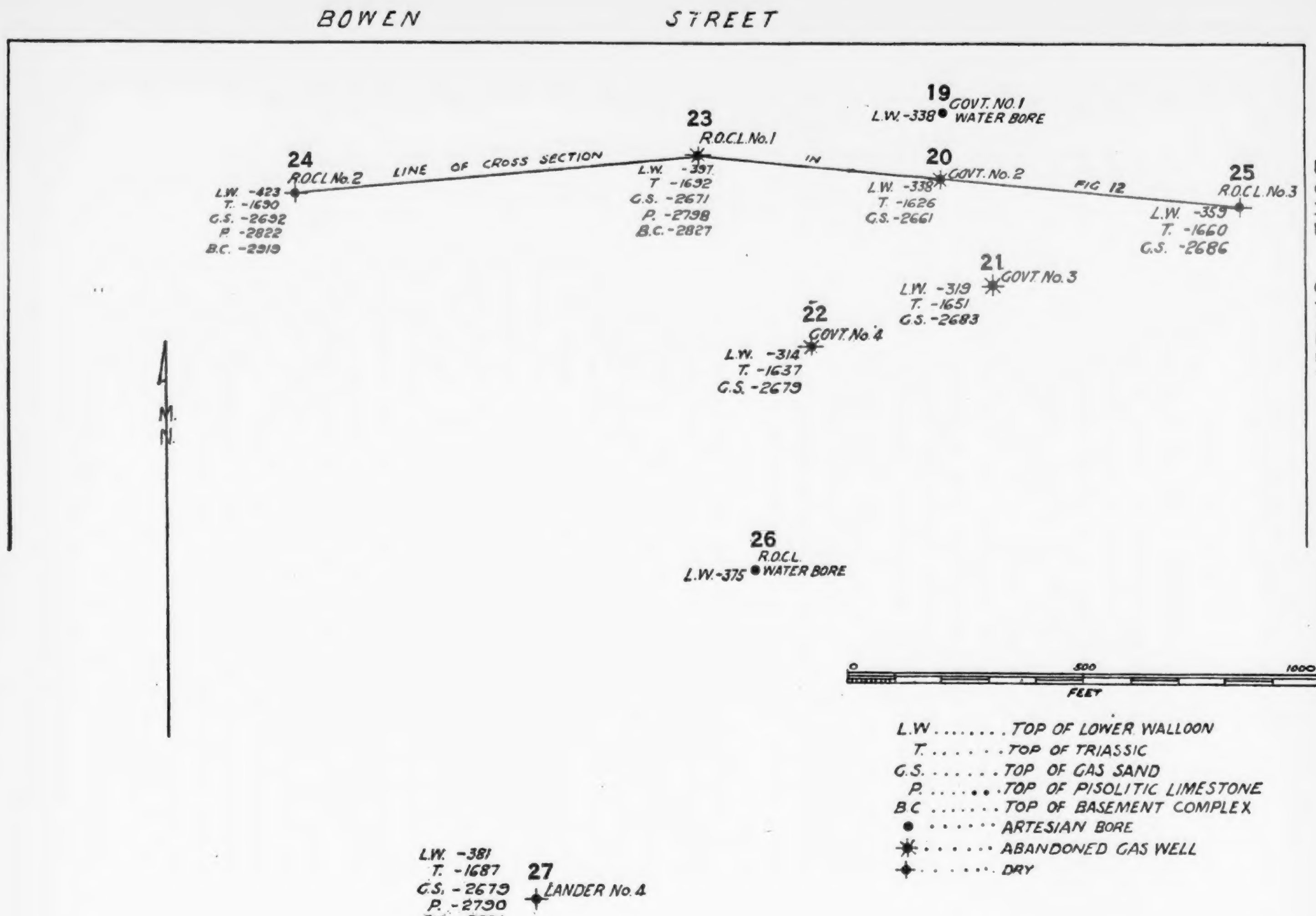

Fig. 8.—Sketch showing wells on Hospital Hill, Roma.

scout bore on the Arcadia dome, in which gas and traces of oil were reported between 195 and 300 feet. In October, 1935, Oil Search Ltd. started a test well on the Hutton dome. The well was drilled with a Commonwealth Government plant to a depth of 4,685 feet and abandoned in 1938, only slight showings of gas having been encountered. In 1936 the same company started a deep test on Arcadia dome. The well was drilled with cable tools to a depth of 4,110 feet, and completed in 1939 with the Commonwealth Government plant to a depth of 6,036 feet. A flow of gas estimated at 250,000 cubic feet was encountered at 1,187 feet, and one of 3,000,000 cubic feet reported below 2,487 feet. Only traces of oil were found.

During 1936-1941, the Roma Block Oil Company drilled four wells near Mt. Bassett, northeast of Roma, which are reported to have found showings of oil and gas. Since 1941 no drilling has been done, but the Shell Development Pty. Ltd. is reported to be carrying out extensive field investigations in the region.

CHARACTER OF GAS AND OIL

The gas encountered in the wells near Roma and at a depth of 1,187 feet at Arcadia, shows the following composition: methane 70–85 per cent, ethane, butane, and propane 5–9 per cent, carbon dioxide 0–5 per cent, and inert gas 2–21 per cent. The gas encountered below 2,487 feet at Arcadia had a high content of carbon dioxide. An analysis shows methane 22.5 per cent, ethane, butane, and propane 3 per cent, carbon dioxide 70.7 per cent, and inert gas 3.8 per cent. The oil collected from the Roma wells ranged from light-gravity water-white oil to dark heavy oil. Some of it closely resembled refined products.

OIL AND GAS SANDS

Most of the gas and many of the oil showings in the Roma wells came from quartz-pebble grits and coarse-grained sandstones 2–5 feet thick near the base of a sandstone formation which, as later shown, is the Bundamba sandstone. The gas sands at Hospital Hill and Warooby Creek, and the oil sand in the Roma Block No. 1 were found in this part of the section. Most of the oil and gas shows at Blythdale came from coarse quartz-pebble conglomerate overlying the granite at depths of 3,800–4,100 feet. The slight showings of gas in most of the wells north of Roma came from sandstones in carbonaceous beds of Jurassic age. The chief flow of gas in the Arcadia well was found in middle Bowen sandstones of Permian age.

FORMATIONS OVERLYING BASEMENT ROCKS

The formations encountered in the Roma wells above basement rocks consist of 0–200 feet of Cretaceous, 1,200–2,500 feet of Jurassic, and 1,000-2,000 feet of Triassic strata. The formations directly overlying the basement rocks are Triassic in age. Figures 9–12 show the correlation of a number of the wells graphically. Table II gives, together with other data, the depths to the top and base

FIG. 8.—Sketch showing wells on Hospital Hill, Roma.

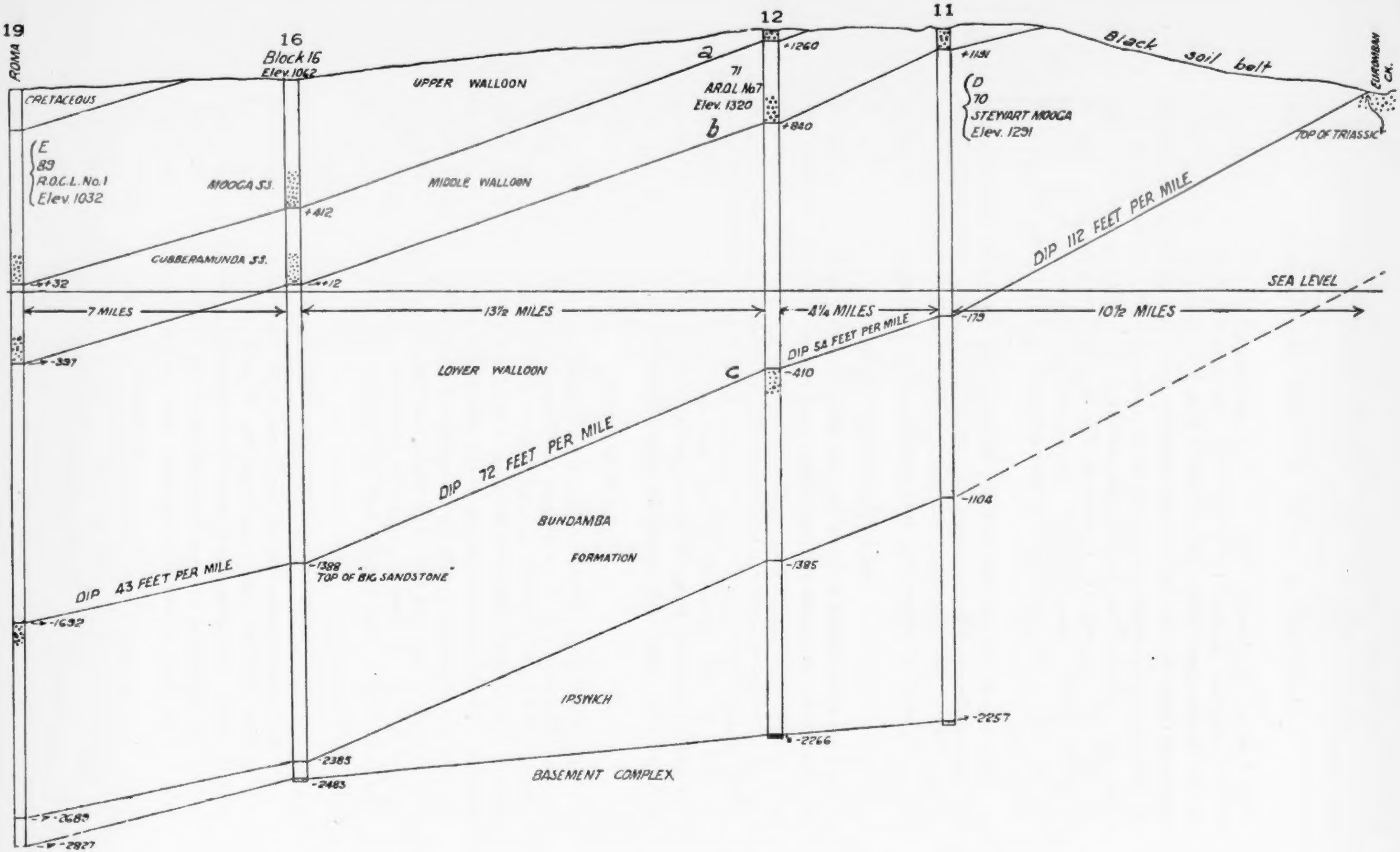

FIG. 9.—Correlation of formations encountered in wells between Roma and Triassic exposures on Eurombah Creek.

of the Bundamba series. The correlations are based on the field work in the region and the study of many cores, rock samples, and drillers' logs. The Mooga and Gubberamunda sandstone can be recognized in most drillers' logs because large flows of water were encountered in them; consequently, they had to be accurately logged. For the same reason the top of the water-bearing "Big sandstone" was also commonly noted. Although this sandstone was generally believed to belong to the Jurassic, it is now evident that it comprises the three sandstone members of the Bundamba series of Upper Triassic age. Its top is the top of the Hutton sandstone and its base the base of the Bundamba sandstone (Fig. 9). The cores from several wells show coarse grit near the base of the sandstone, in which most of the gas and showings of oil in the Roma district were encountered. As noted earlier, the Bundamba sandstone at its outcrop in the Carnarvon Range contains pebble conglomerates and coarse-grained sandstones in its basal part.

Below the Bundamba series and above the basement are many rock types which commonly consist of dark, carbonaceous sandy shales in which are micaceous sandstones, greenish shale, and green pebbly grits with thin beds of coal and tough oil-shale. In two wells on Hospital Hill (Fig. 12) oölitic limestone 2–4 feet thick was encountered 110 feet below the base of the Bundamba. The shales encountered below the Bundamba are much more indurated than those higher in the section. Core samples do not crumble when exposed to the air like those of higher shales. Because of their position below the Bundamba this series of shales was assumed to be the equivalent of the Moolayember shale or Ipswich series. This tentative correlation was later corroborated by finding Triassic plant fossils in these shales in Lander No. 4 at depths of 3,726 and 3,800 feet.

The thickness of these shales varies from 100–200 feet on Hospital Hill to more than 1,000 feet in the Stewart Mooga well, 23 miles northeast of Roma. In the Wallumbilla well 1,192 feet were encountered without striking basement rock.

FORMATIONS IN HUTTON AND ARCADIA WELLS

The Hutton well encountered 657 feet of sandstone immediately beneath the surface. Approximately the upper 250 feet of this is the Bundamba sandstone; the remainder may be the Carnarvon sandstone. From a study of rock samples and cores, Miss Irene Crespin (1945) concludes that the balance of the well was in the middle Bowen series (Fig. 13). She has subdivided the strata below a depth of 657 feet as follows.

Feet	
657– 886	Marine sediments containing Foraminifera and brachiopod remains
886–3,959	Fresh-water sediments with plant remains
3,959–4,686	Mixed assemblage of marine (Radiolaria) and fresh-water fossils (plant remains)

The presence below 3,959 feet of dips of 30–60°, fracturing, and slickensides, suggest that the well encountered a fault zone at 3,959 feet. As noted earlier, surface evidence of a fault was observed on the west flank of this structure, 3,000–3,500 feet west of the well.

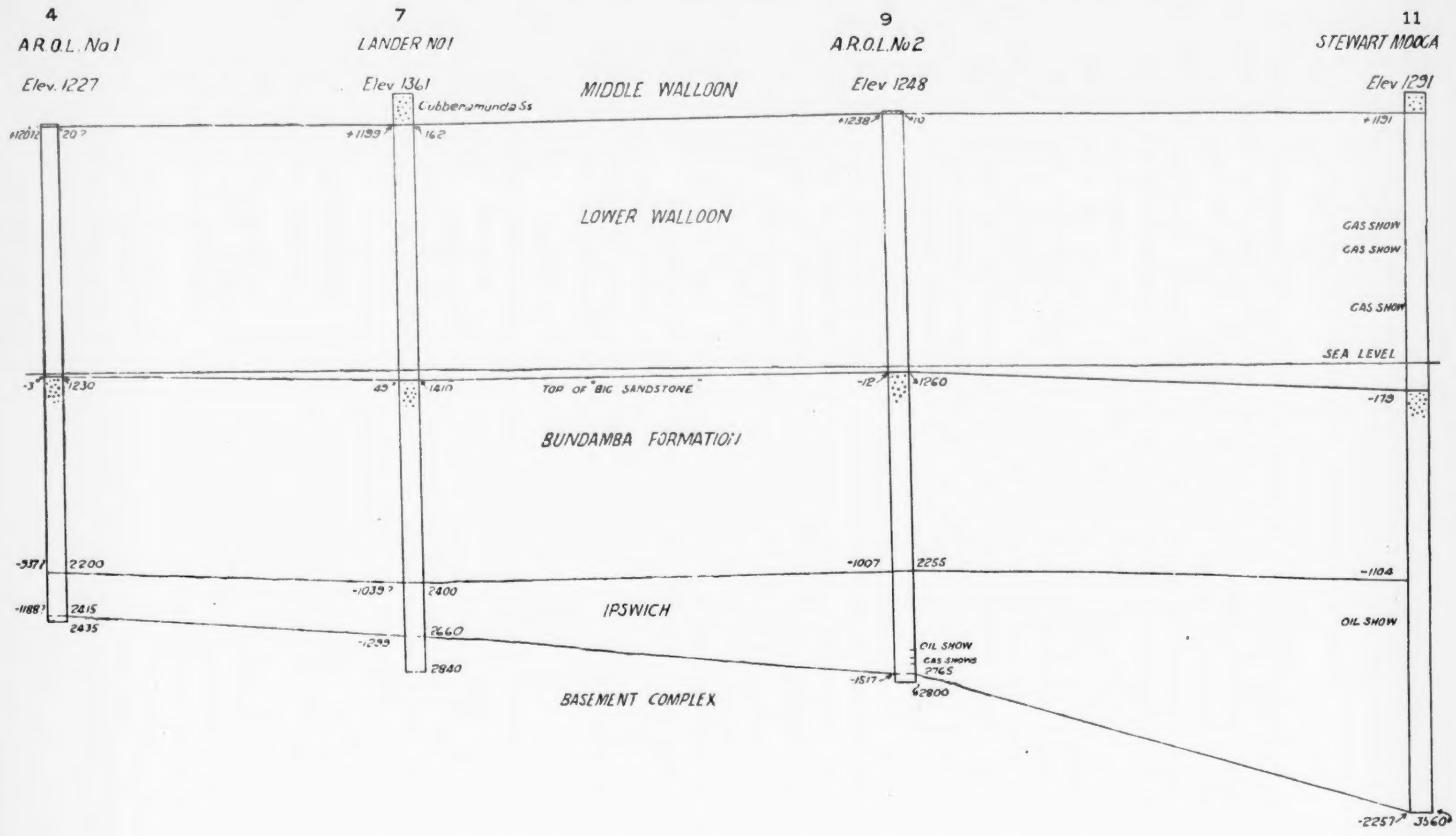

FIG. 10.—Correlation of formations encounterεd in wells westward from Stewart Mooga well.

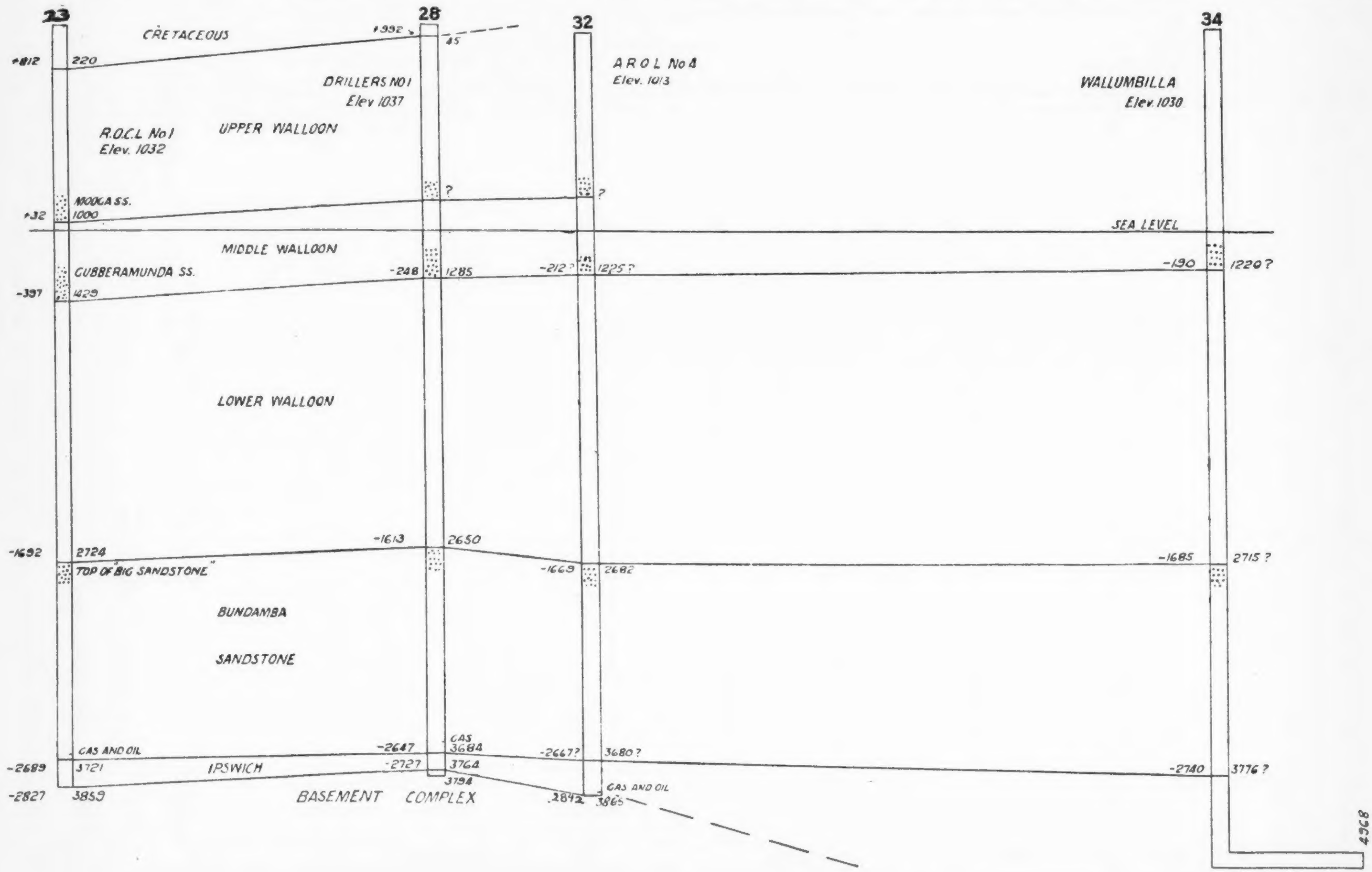

FIG. 11.—Correlation of formations encountered in wells between Roma and Wallumbilla.

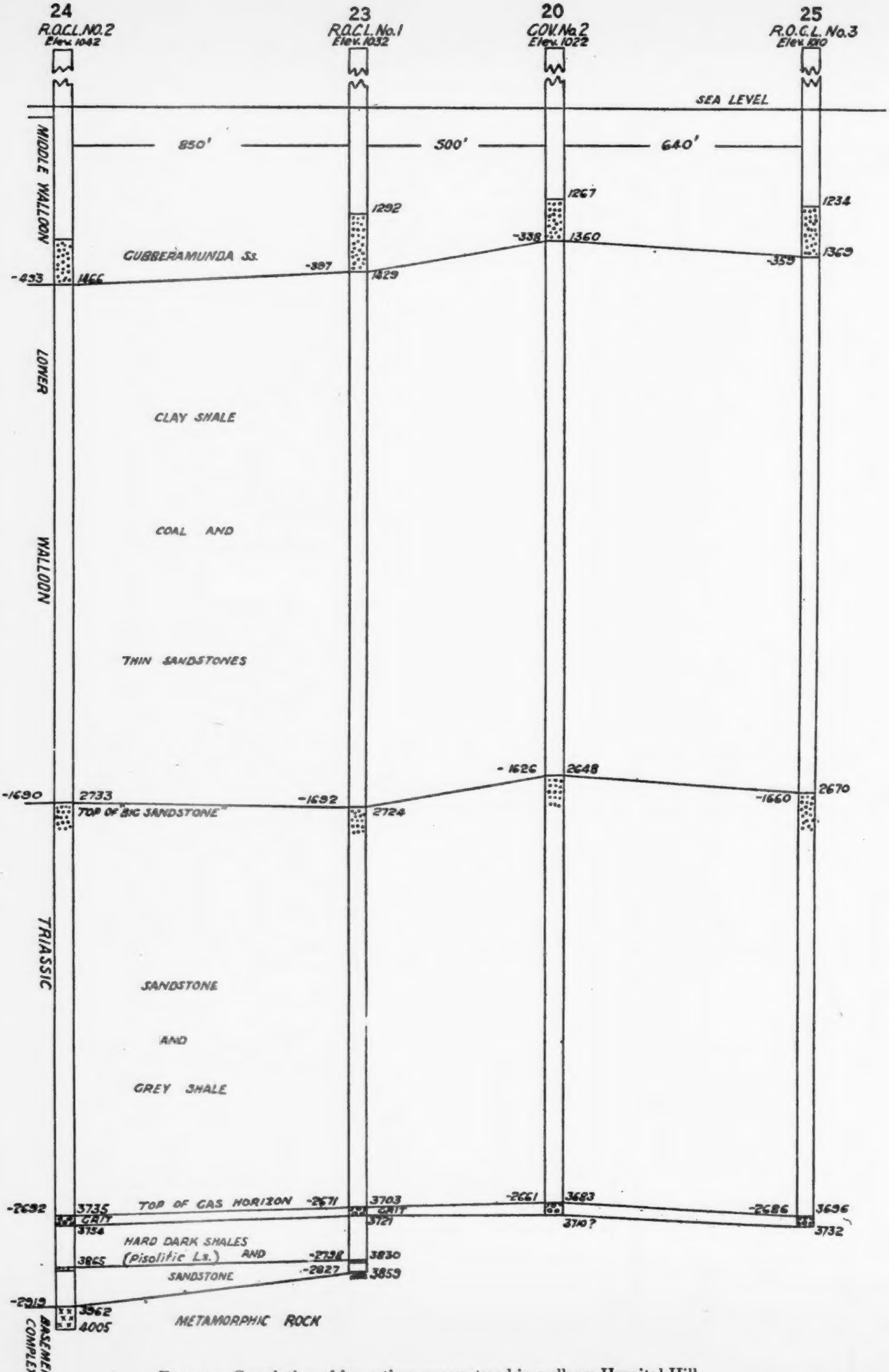

FIG. 12.—Correlation of formations encountered in wells on Hospital Hill.

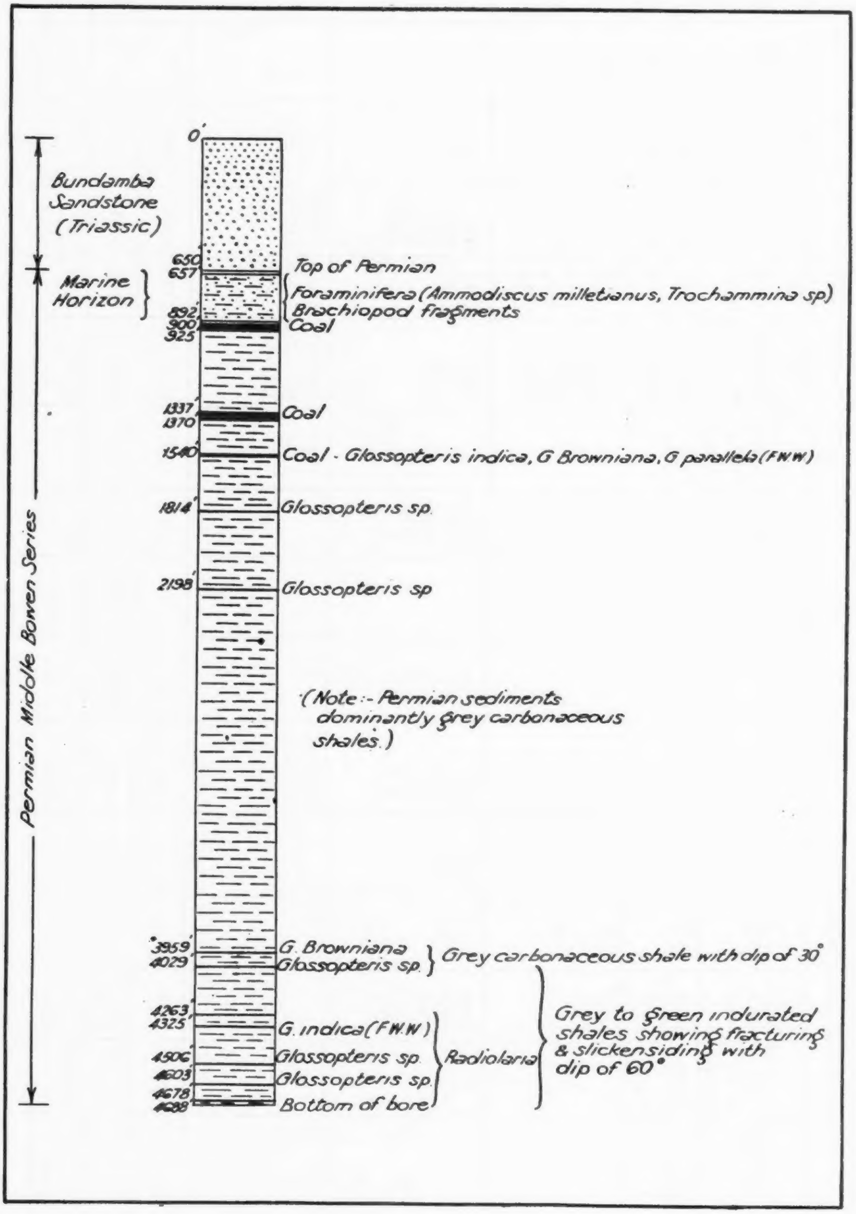

FIG. 13.—Diagrammatic log of Hutton Creek bore. (After Irene Crespin.)

TABLE II
DATA ON WELLS DRILLED IN ROMA DISTRICT

Map No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Company	Kayenta	Corn-wall Dome	Roma Dome	AROL. No. 1	Lander No. 2	Lander No. 3	Lander No. 1	Roma Oralla	AROL. No.2	Queens-land Roma	Stewart Mooga	AROL. No.7	AROL. No. 3	Mid-Contin-ental	Inter-state	Roma Block No. 1	Warooby Mt. Bassett
Elevation	1539	1340	1412	1227	1465	1363	1361	1173	1248	1223	1291	1320	1150	1143	1065	1062	1232
Year completed	?	1930	1928	?	1924	1926	1924	1930	?	?	1931	1932	1929	1929	1931	1929	1912
Water Encountered		?	106 1823	1215 1273 2145	530		132	?	1510 1585 2650	?	550 1480 2270 2820 3175	460 1897 1950 2036 2584	?	500 760 800 1417	394 628 730	565- 585	?
Gas Shows			265 1300- 1320 1875- 1885	175- 180	2596- 2606	1882 1925-69 2181 2265 2348	250 436 496 868		2685- 2687 2710- 2730		685 785 1185	2711 3435	2095 2530 2947 3000- 3008	1440 1872		1255 1290 1360 3507	
Oil Shows						2181-86 2348-50				1835? 2760	3318-57 3427-28 3447-50	3200 3430- 3462	2300? 2335?			3445- 3447 (Few glns) 3503- 3510	
Depth to Top Triassic	1170?	1370?	895	1230	1435?	1425	1410	1650	1260	1260?	1470	1730	1825	2300?	2412?	2450	
Depth to Top Ipswich		2370?	1910?	2200?	2388	2416	2400?	2650?	2255		2395	2705	2781			3447	
Metamorphics Granite	2060	2700?	2226	2413		2660	2660	2835	2765		3510	3586	3128			3545	
Total Depth	2104	2706	2255	2433	2625	2670	2840	2863	2800	2789	3560	3610	3150	3080	2705	3561	2000

18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
AROL. No.14	Govt. No.1	Govt. No. 2	Govt. No. 3	Govt. No. 4	ROCL. No. 1	RCCL. No. 2	ROCL. No. 3	ROCL. Water Bore	Lander No. 4	Drillers No. 1	AROL. No. 8	AROL. No. 5	ROCL. No. 4	AROL. No. 4	AROL. No.11	AROL. No.19
1125	1022	1022	1021	1027	1032	1044	1010	1021	1016	1037	1030	1008	999	1013	971	1030
1931	1897	1899	1907	1919	1927	1928	1929	1929	1929	1935	1930	1930	1930	1930	1931	1934
108 126 280 3521	907 1298- 1360	927 1290- 1358	975- 1040 1260- 1338	530- 542 1000 1342	912- 980 1292- 1429	399- 474 2370 3898- 3906 (Saline)	1776- 1796 3527 3541	1332- 1392 1385	1333- 1335 1570- 1586	1800 3200 3764			1160 1400 2200	189 3288 373 3568 464 3850 542 645	3971- 3977	511 680 3612- 18
3399		3683 (40,000 cubic feet)	3702 10,000,000 cubic ft. Burned 3 months	3705 22,000,000 cubic ft.	3703 600,000 cubic ft.	3910- 3918 30,000 cubic ft.	3630-34 3696-04 3709-11	183 1050	3285 3409 3533 3621 3658- 3739	3629-60 650,000 cubic ft.	3861-65	3026-49 3061-86 3104-22 3185-92 3214-23 3532-41 3736-38	3212-17 3676-86	1834 2512 3844-48 3850-60	3496 3913	
3399					3400 White oil at 3703	Heavy oil at 3910-19	3630-34		3658- 3739		3861-72	3776-84 3829-34	3822-39	3844-48 3850-60	4095 4124	
2194		2648	2670	2663	2724	2733	2670		2702	2650	2668	2645?	2650	2682		2715?
3115?		3710	3663?	3677?	3721	3754	3721		3718	3684	3653?	3656		3682?		3776?
3535					3859	3962			3836	3764	3871			3865	4130	
3542	1678	3710	3713	3709	3859	4005	3732	1518	4158	3794	3988	3848	3839	3902	4162	4968

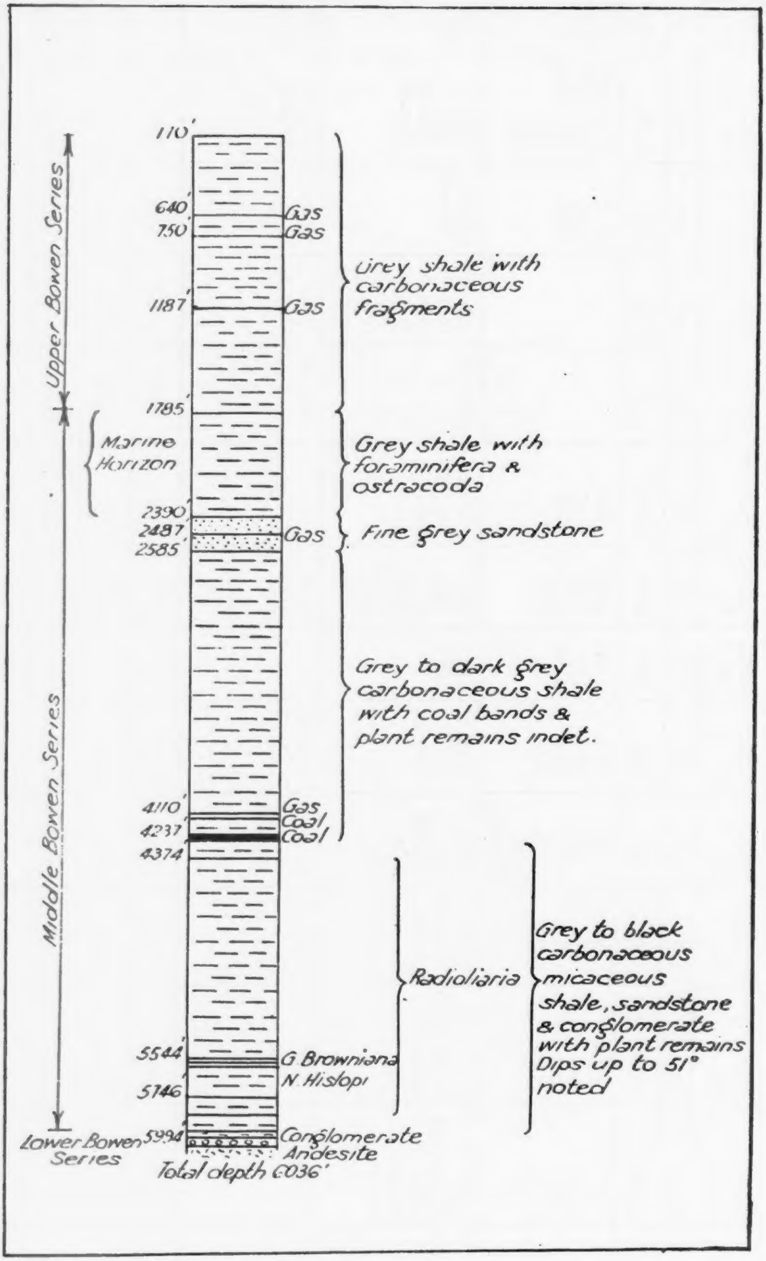

FIG. 14.—Diagrammatic log of Arcadia bore. (After Irene Crespin.)

The Arcadia well started in the upper Bowen at 2,000 feet below the base of the Carnarvon sandstone. The formations penetrated in the well, according to Miss Crespin, may be subdivided as follows (Fig. 14).

Feet		
0–1,785	Upper Bowen fresh-water sediments	
1,785–5,994	Middle Bowen	
	1,785–2,390	Marine zone
	2,390–4,374	Fresh-water zone
	4,374–5,994	Mixed marine and fresh-water zone. Dips as steep as 51° noted
5,994–6,036	Lower Bowen andesites	

BASEMENT ROCKS

More than half of the wells in the vicinity of Roma penetrated granite or metamorphic rocks. The granite commonly shows deep weathering, and in some wells is covered with coarse granitic agglomerate. The metamorphics rocks consist of buff and greenish talcose schists, black slaty shales and quartzites. One well (No. 27) penetrated more than 300 feet of metamorphic rocks without encountering granite.

The top surface of these basement rocks forms a broad ridge that plunges southeastward between Alicker and Blythdale (Fig. 15). As a rule, granite forms the surface of the ridge along its crest and metamorphic rocks on its flanks. In the most northwesterly well (No. 1, Fig. 15), 45 miles northwest of Roma, granite was encountered at a depth of 2,060 feet. In the most southeasterly well (No. 33), the granite was penetrated at 4,130 feet. The slope of the ridge to the southeast is therefore about 80 feet to the mile, or about the same as the dip of the overlying Triassic rock. The surface of the ridge, however, is somewhat irregular and probably has considerable relief. The difference in elevations of the surface of the ridge in two adjacent wells on Hospital Hill (Nos. 23 and 24) and two at Blythdale (Nos. 32 and 33) shows slopes, respectively, equivalent to a fall of 564 and 418 feet to the mile. East of Blythdale the surface of the ridge falls off at an unknown rate. The Wallumbilla well (No. 34), although drilled approximately 1,000 feet deeper than the Blythdale wells, did not reach basement rocks. Likewise, the slope of the ridge must be pronounced northeast of the Stewart Mooga well (No. 11), for no basement rocks were encountered in the Hutton and Arcadia wells, although they penetrated strata 4,000 and 8,000 feet, respectively, below the Ipswich series, which directly overlies the basement rocks at Roma.

The age of the granite and associated rocks is not known. The granite may be Devonian or older. On the other hand, it may be of the same age as the Permian granite at Cracow. If it is older than the Permian, it may have existed as a ridge in late Paleozoic time and was overlapped by Permian fresh-water and shallow-sea deposits. If it is late Permian in age, then the Permian formations will be found either in fault contact or tilted away from it. At any rate, it evidently was base-levelled in early Triassic time and covered by transgressive Middle Triassic sediments. At the close of the Cretaceous, when the Great Artesian Basin took its present form the Mesozoic as well as the underlying basement rocks in the area north of Roma acquired their present southerly tilt.

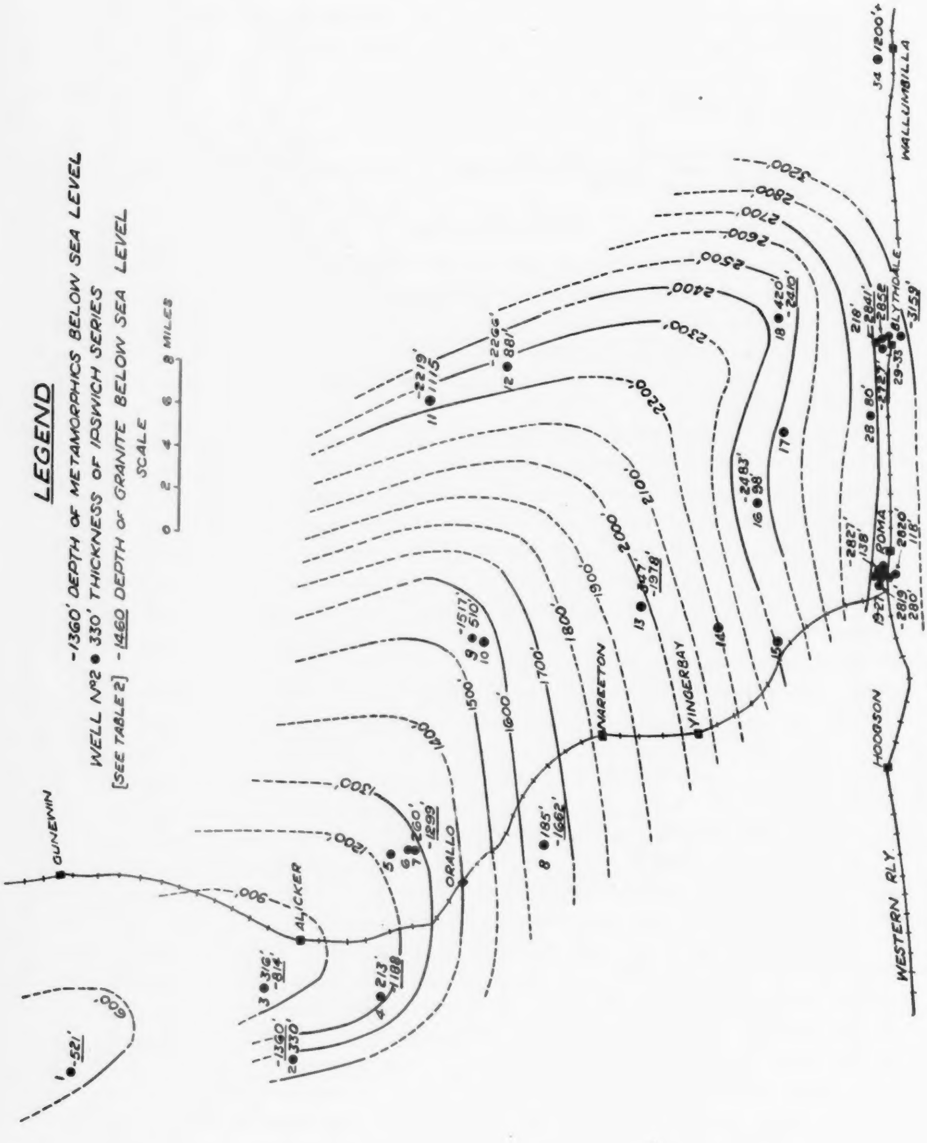

FIG. 15.—Contour map showing elevation of basement rocks below sea-level in Roma area.

FIG. 15.—Contour map showing elevation of basement rocks below sea-level in Roma area.

Oil and Gas Possibilities

As the Jurassic and Triassic formations are entirely fresh-water in origin, and the Permian contains only thin marine stages, the prospect of finding commercial oil fields in the area under review is not very promising. This conclusion is supported by the meager showings obtained during nearly a half century of drilling, and by the fact that no surface traces of oil have been reported throughout the entire Dawson-Bowen sedimentary basin. But in view of Australia's need of indigenous supplies of oil, any area offering the slightest chance of yielding appreciable volumes of oil should be thoroughly explored. It is evident, however, that if further drilling for oil is to be done in the area it should be confined to structures northeast of the basement ridge that are underlain by Permian strata, and to localities on the northeast flank of the ridge where the Permian is overlapped by the Triassic and may itself transgress the lower slopes of the ridge.

The prospects of developing commercial supplies of gas in the vicinity of Roma also are not very good. The gas sands in the Ipswich series are too thin to hold a very great volume of gas and are, moreover, partly occupied by water. The thick Jurrasic sandstones appear to be entirely filled with water. The Permian contains sandstones of considerable thickness and fair porosity interbedded with carbonaceous sediments, and commercial supplies of gas may possibly be found in them. The gas, however, encountered in the Permian in the Arcadia well is too high in carbon dioxide for use as a combustible gas.

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OIL-RESERVE PROVINCES OF MIDDLE EAST AND SOUTHERN SOVIET RUSSIA[1]

F. JULIUS FOHS[2]
Houston, Texas

ABSTRACT

The Persian Gulf geosyncline is the result of the pushing southwest of the Alpine arc of the Tauros-Zagros (Kurd) Mountains against the Arabian lobe of the Gondwanda (North African) shield, a stable block creating a great foredeep with more than 30,000 feet of sediments of Carboniferous to Recent beds, principally Cretaceous, Tertiary, and Pliocene in age.

In this basin a considerable number of secondary anticlinal folds constitute the *loci* of great oil pools, principally now from the Asmari (Eocene-Oligocene) limestone. There are 20 developed oil pools with 150 wells capable of an annual production of 1,600,000 barrels, and much gas; in 1946 production was 729,000 barrels. Northeast of the Zagros Mountains and south of the Elburz Mountains are one second-class and three third-class basins with undeveloped oil possibilities, mostly of Rocky Mountain type.

In southern U.S.S.R. is the Caspian Sea province consisting of three great east-west synclinal basins with beds from Devonian to Recent but principally of Permian to Tertiary strata. Here have been developed the Baku and other fields, but development to date is minor. These basins with extensions westward into Russian-controlled Balkan states and other undeveloped basins, with older beds, at the north, give Russia large oil reserves, though 1946 production was only 555,000 barrels.

The Middle East has 975,000 square miles of oil-gas basins; two-thirds promising for first-class pools. Southern U.S.S.R., inclusive of Balkan areas, has 1,048,000 square miles of primary areas, and 93,000 square miles of secondary areas. Thus, Russia controls in this region alone oil deposits as important as those of the Middle East. It is safe to estimate future ultimate oil reserves of the Middle East and Russia, each at 100 billion barrels, and United States at 50 billion barrels. Of Middle East reserves Britain controls more than United States nationals but they own a somewhat greater area.

Herein is an outline of the tectonics of these regions as a background for a discussion of their petroleum reserve areas, and a quantitative guess-estimate. Because of the international, political, and economic relationships of oil, it appears important to compare Soviet Russia's position with that of the Middle East. The writer has in preparation a larger study of Soviet Russia (U.S.S.R.) and Russian controlled Balkan countries, but restricts the comparison here to such parts of both as are contiguous to the Middle East. The Russian dominated Balkans include Hungary, Roumania and Bulgaria, and Poland. The new boundary which gave Russia eastern Poland, practically denuded Poland of oil reserves, and added its sub-Carpathian deposits directly into the Russian column. Gester (11)[3] has previously given oil-reserve outlines of the Middle East and Russia in his paper on the world's oil reserves, and DeGolyer (6) has written of Middle East reserves, but the map (Fig. 1) here given is the writer's own interpretation.

It is important to classify the reserve areas under discussion as primary, secondary, and tertiary, to stress basic geologic relationships, and to indicate the

[1] Manuscript received, April 18, 1947.

[2] Consulting geologist. Appended is a select bibliography, much of which was used in the preparation of this paper, and to which due acknowledgment is hereby made. In a few instances direct reference is made in the text by the numbers given the references. The writer is indebted to W. C. Mendenhall, former director of the United States Geological Survey, for use of material from the Survey library, and to Basil B. Zavoico for loan of important Russian papers and maps.

[3] Numbered references are given at the end of this article.

relative value of the provinces. In primary, are included very large oil-gas reserve potentials; in secondary, those containing reserves in important quantity or capable of being developed as such, but of lower potentials; and in tertiary, areas while worthy of exploration, either only possible or of small potentials. Emphasis is placed on the presence of vast basinal areas with great thickness of sedimentary rocks, and with large oil and gas potentials.

The foreland influencing the formation of the present orogeny of the Middle East occupies the west half of Arabia and is an eastward continuation of North-African Gondwanaland, an east-west rectangular tableland. This is an old stable block or segment of Paleozoic and pre-Paleozoic age permeated with old crystalline rocks and granites, and stable within itself for a long period of geologic time; this block has some large cracks through it such as the Red Sea. The next most important influence is that of the Taurus Mountains of Turkey and their continuation,—the Zagros Mountains of western Iran. These mountains form the Asiatic continuation of the Alps, represented eastward by the Himalaya Mountains of northern India, and westward by the mountains of Greece, Dalmatia, and northern Italy. The Taurus-Zagros Mountains consist of highly folded and faulted beds of pre-Cambrian crystalline rocks, Jurassic limestones, Cretaceous limestones and shales, and more recent beds.

Paralleling these mountains on the southwest is a group of long and short steep folds here referred to as the Mosul-Ahwaz group, in which occur the principal oil fields of Iran and Iraq. These folds continue, but are smaller and less well delineated, westward into northwestern Iraq and northern Syria. They occur in a syncline of great depth and magnitude (Fig. 2). In southeastern Turkey and northern Iraq the Tigris and Euphrates rivers originate. There are 550 miles of these folds in Iran; the southeasterly 300 miles contain a scattered group of salt domes.

A group of folds flanks the foreland on the northwest in Syria and on the west in Lebanon, Transjordan, and Palestine; these folds are largely in limestone beds and lack proper sealing cover; basalt flows also intervene; hence, the oil-gas possibilities are limited. Along the coast in Palestine some Miocene beds appear, but there also the prospects are limited; a few domes in southern Palestine may have ample cover, but due to lack of it, most of the structures and faults in Palestine and the Levant states are of little value.

These Syrian folds spread fan-like; the eastward-flanking mass of lava, Eocene and Cretaceous beds, has an overlap on the northeast of Miocene beds, principally of the Fars series of sandstones, gypsum, and shales, with some salt, as far as northeast of the Euphrates River, where it is broken by some basalt flows and merges with the main southeastward-plunging syncline.

In this syncline, the delta of the Tigris and Euphrates rivers has a covering of Quaternary overlying the Miocene and probably to a greater extent the Bakhtiaris (Kurd) series of sandstones, red shales, and gypsum. These Pliocene beds are as thick as 15,000 feet in the ridges east of the Tigris River. Together with

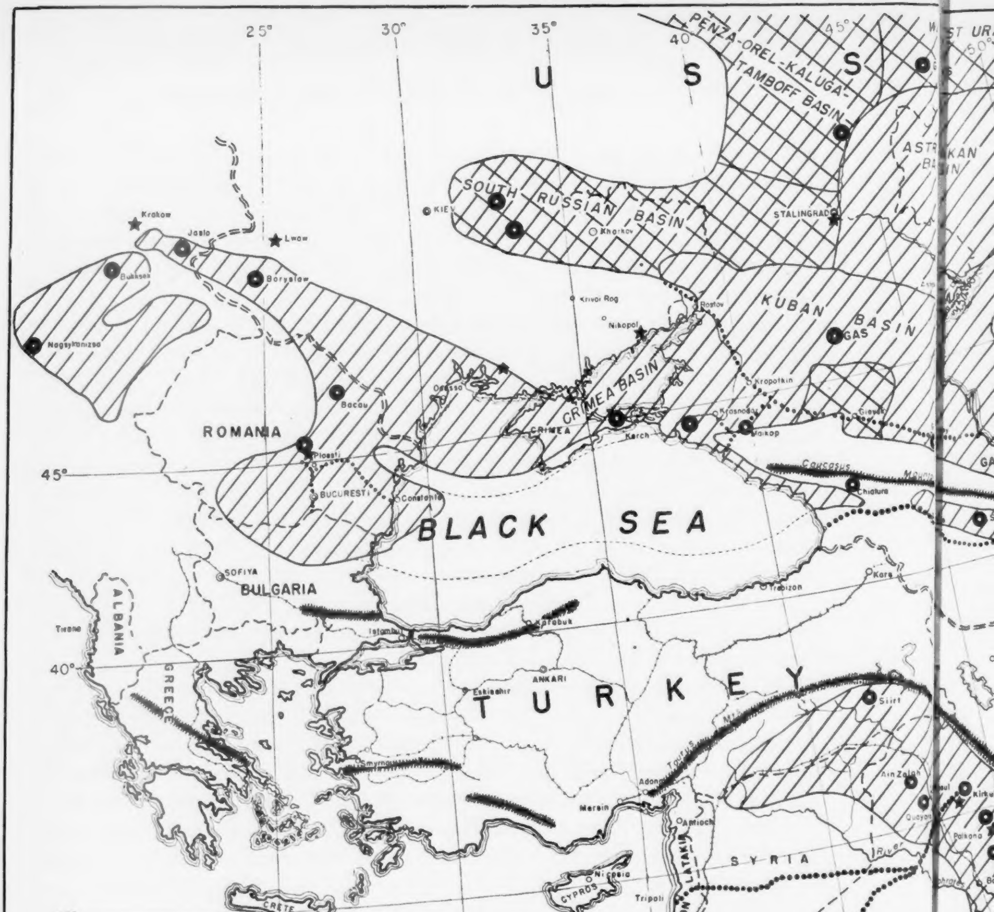

FIG. 1.—(West part).

FIG. 1.—(East part).

FIG. 1.—(West part).

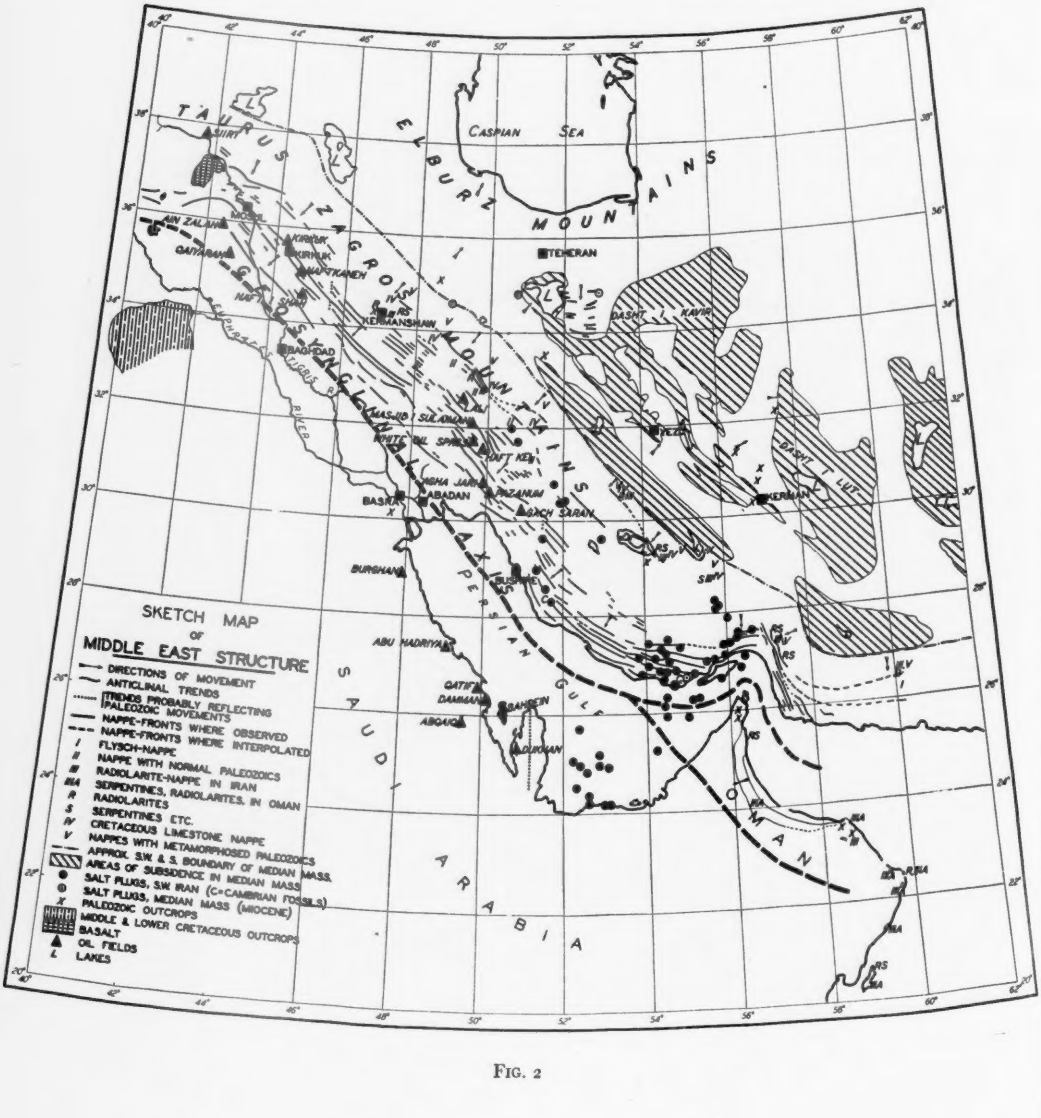

FIG. 2

FIG. 1.—(East part).

the Eocene, Jurassic, and Cretaceous, this basin at the mouth of these rivers must have at least 30,000 feet of sedimentary strata, though some geologists estimate 50,000–60,000 feet.

Farther south, east of the Arabian foreland, is an overlap of Cretaceous and Eocene beds, partly pierced by lava overflows. In southeast Arabia is the Oman Range, which consists of Cretaceous, Eocene, and some older beds. These mountains strike north and, though appearing to be a virgation of the Zagros Mountain folding, are probably not related to them. The folds, in older beds, such as those on Bahrein Island and others in the vicinity, possibly are influenced by the Oman Range. This range is flanked on the east with Miocene beds. On the west flank of the range important buried secondary folds should occur somewhat in line with Abqaq.

The Euphrates-Tigris-Shatt-el-Arab river system rising in the Taurus Mountains of Turkey is similar to the Mississippi River, rising in or near crystalline rocks west of Lake Superior and following southward an ever-deepening geosyncline to the Gulf of Mexico. Also like the Mississippi, it has added to its delta large sedimentary deposits, carried chiefly from the mountains north and east, to form newly made delta land, which since 1860 has extended several miles into the Persian Gulf. The Persian Gulf basin covers 687,000 square miles, of which 592,000 square miles constitute primary exploitable area. This is comparable with a *total land area* for the Gulf Coast-Mississippi River embayment of 190,000 square miles, inclusive of northeast Mexico.

On the south end of the Mosul-Ahwaz group of folds in Iran, are many old, possibly Triassic-Jurassic salt domes,—and similar domes occur partly as small islands in the south half of the Persian Gulf and near the coast, northeast of the Oman Range in Arabia. Basic extrusions occur on the south and east coast of Arabia and form part of a separate mountain system.

The African-Arabian foreland is the rigid block against which the Balkan-Alpine arc pushes southwest in the eastern Mediterranean; another Persian-Afghanistan-Baluchistan arc of similar import pushes south with the Zagros Mountains as its west limb. This moving Balkan arc compressed the folds of western Syria, Palestine, and northern Transjordan to give the ramp effect of which Baily Willis writes. This replaces the idea of rift valleys of which Gregory, Blanckenhorn, Blake, and others have written After long consideration, the writer accepts the Willis theory as more probable; the depression of the Jordan-Dead Sea-Ghor appears to be a ramp, not rift valley. It is a narrow, greatly compressed synclinal mass of sedimentary beds which are thicker toward the Dead Sea. Likewise, the writer does not consider the Red Sea a rift valley, though it is bounded by large faults. The south end of the Dead Sea graben extends into the Arabian foreland mass; the Red Sea cuts through and into this mass on a greatly enlarged scale.

In the primary oil-reserve area of Saudi Arabia, it is estimated that there are 221,000 square miles with a westward secondary area of 100,000 square miles almost unexplored. A tertiary area, 90,000 square miles, adjoining the latter on

the west, and of much lower potential, is the Karst zone flanking the Arabian foreland on the east with the beds rising toward the foreland; in this shallower zone oil deposits may occur in pinch-outs, minor folds, and faults. However, the possibilities of the primary area are so great and will require such large resources and so much time for development, that the other zones will not be developed for some time.

Within the median mass on the north are only basins of secondary and tertiary value for oil-gas. The best of these, in northern Iran and southwestern Afghanistan, covers an area of 175,000 square miles and has exposed structural domes with Cretaceous at the surface—some more buried than others, with scattered igneous flows. This basin is of uneven value and almost wholly unexplored as well as difficult of access both for exploration and pipelines. That it will ultimately yield pools of the Rocky Mountain type, there seems no doubt. It was studied by Frederick G. Clapp, Frank Reeves, and others (5).

Southward in Iran are the Kerman and South Iranian basins, and on the east, the Central Baluchistan basin, totaling 97,500 square miles. The Kerman basin possibly has some igneous intrusions; all three basins are unexplored but are possible areas.

Along the Oman Gulf shore of Iran and Arabian Gulf shore of Baluchistan, is the eastward continuation of the Persian Gulf basin of 52,000 square miles of primary possibilities.

Reserve values in the primary province vary greatly in different parts of the area; thus, the northern two-thirds of the British area in Iran, and a strip 50 miles wide in eastern Iraq are ultra-rich, as is the strip on the west coast of the Persian Gulf from Trucial Oman north.

The secondary area in northern Iran—Afghanistan—is comparable with the Big Horn Basin in the Rocky Mountains, and only a small part of this was included in the Russian concession—that just east of Teheran. Gester includes the Caspian Sea-Persian Gulf provinces as one great oil center, but their only genetic relationships may have been some similarity of climatic conditions, since several orogenies are involved.

Turkey's oil territory is small, chiefly in the Ardahan province to which Russia has recently indicated claim.

The blocked-out reserves are only a fraction of those to be developed. It is reported that there is blocked out in the Persian Gulf area 16 billion barrels and an indicated province reserve of $26\frac{1}{2}$ billion barrels. It is not unreasonable to expect 100 billion barrels ultimate. The fuel oil and/or gasoline equivalent of natural gas is not included, and will add 50 to 60 per cent additional to this over-all oil reserve.

North of the Asiatic Alps, is a median mass of crystalline rocks, older rocks, Jurassic, and eruptives, and on the north edge are the Elburz Mountains of northern Iran and their extension northwest through Turkey. On the north flank are secondary folds (it is probably these folds that Russia sought in her recent

Iranian concession), and while the land area covered is only a narrow strip on the south shore of the Caspian Sea, it does spread toward the west at Resht and toward the east, south of the Soviet oil field, Chikishlar, and into the Caspian.

This forms part of the Baku basin, which in turn is bounded on the north by the Asiatic Altaids of which the Caucasus Mountains, and Hindu Kush, are representative. This great line of uplift extends westward through Crimea to the Roumanian-Bessarabian boundary, and eastward through Turkmenistan and northern Afghanistan. The Baku basin covers 97,000 square miles, of which 70,000 square miles are exploitable.

Another geosyncline, the Kuban-Uzbek-Turkmen and extensions, is bounded by the Altaids on the south and by a lesser line of uplift extending from the Donetz basin eastward through the Caspian peninsula and into China with the Hissar-Tian axis. This covers 443,000 square miles, of which 428,000 square miles may be exploited. In the Caspian off shore from Daghestan and Baku are particularly important probable oil areas, as against predominant gas in the land surfaced Daghestan anticlines. Recent development of a new pool $4\frac{1}{2}$ miles east of Baku in the Caspian Sea, is indicative of these possibilities as this pool is considered to have potentialities equal to the best of those on the Apsheron Peninsula. The great draft upon these pools in the war needs replacement and only drilling in the sea and deeper drilling of the older pools will answer. There should be production as deep as the Devonian, where most of the production is still from Pliocene, Miocene, and Oligocene. Aside from the sub-Caucasus fields of Maikop and Grozny, the gas fields of Daghestan, the Baku (Apsheron Peninsula) oil fields, and the less important Termez fields at the extreme east of the basin, this vast area of large potentiality remains unexploited.

North of this is the Astrakan-Emba-Kazakh-Ferghana basin covering 448,000 square miles with great thickness of sediments from the Volga, Ural, and Emba rivers in the Astrakan-Emba region. Thus, the Caspian Sea has three synclinal basins crossing it east and west with a total of 946,000 square miles of primary oil-reserve areas and quite distinct from the Middle East basins, but equally rich.

Astrakan and Emba, where sedimentary beds are thickest, are salt-dome basins, gas having been found in the former and Jurassic, Cretaceous, and Permo-Triassic oil in some quantity in the latter, but both require deep drilling. At the extreme east is Ferghana, a semi-closed valley with several oil fields.

Productive fields are in the South Russian basin and immediately north in the West Ural-Moscow basin, where good fields have been developed with production ranging from Permian to basal Devonian age. These belong in the secondary category, are only partly exploited, and the deeper zones are barely touched in a few fields; much oil and gas may be expected from them; the new Devonian production on the southwest flank of the Urals, possibly should be classed as primary. The Ob-Irkutsh basin just north of the Kazakh basin represents a vast unexplored region with good prospects especially on the west limb in the sub-Ural region; the beds are probably Permian and older, though now covered by younger beds. On

the east side of the basin is an old foreland, and the movement of the Urals, with the aid of this stable block, has probably provided ample folding. The lower Ob basin, in the Arctic and sub-Arctic regions, will doubtlessly be exploited only at a much later time—and there are other exploitable regions in Siberia which do not come within this purview.

Additionally, Russia has under her control in the Balkans 99,000 square miles including the lower Danubian basin in Roumania and Bulgaria, the Transylvanian basin, and the Hungarian basin. The lower Danubian includes the oil fields of the sub-Carpathians, and development has now been slightly extended into the gravel-covered plain. Most of the Roumanian production has been from the southernmost part of the sub-Carpathian area, partly from salt domes. Its high productivity is well known and with only a small part of the plain exploited, many new pools are yet to be found. Adjacent Bessarabia, though somewhat less promising, is well worthy of development. It is believed that no one has previously shown the Black Sea to be principally basinal, crossed by the last two basins. The Transylvanian basin has supplied mainly gas and the Hungarian basin, though oil-productive, belongs also in the secondary category. Destruction in the war was material, but production has been restored to about the same daily output as pre-war.

Ownership of Middle East primary exploitable reserve areas is divided in approximate square miles as follows: American companies 292,000, British-Dutch 233,000, French 37,500, C. S. Gulbenkian and associates 7,900, Turkey 21,500 and a small area in northern Iran owned by Soviet Russia. On basis of control, however, Britain has 318,500 as against 252,000 square miles under American control. In addition, as Figure 1 indicates, there are sizable secondary and tertiary reserve areas.

DEVELOPMENT

The number of pools developed thus far is small, for example, only one domal area on an anticline where three may exist as at Kirkuk. In other words, development of known structures is relatively slight, and because of the considerable number of structures and the great productivity of those already developed, only the most promising, obvious, and easily accessible will be exploited soon. Thus there are a few pools developed in eastern Iraq, in northwest Iran, and a few near the west coast of the Persian Gulf from Kuwait through Saudi Arabia, Bahrein Island, and Qatar. The daily production in 1946 was 729,041 barrels, and it is estimated that this will be increased to 1,600,000 barrels as soon as facilities are completed in 3–5 years.[4]

Likewise in Soviet Russia, development has been restricted principally to a few areas, and only those of the Apsheron Peninsula, Grozny, and Maikop have yielded oil in quantity. Russian production in 1946 was estimated[5] inclusive of

[4] *Oil Weekly*, Vol. 124, No. 11 (Yearly Forecast, February 10, 1947), pp. 79 and 80.

[5] *Ibid.*

Sakhalin at 454,794 barrels daily but may have been greater; additional Russian controlled production is about 120,289 barrels, giving Russia a total of 575,085 barrels daily in 1946.

In summary, the Middle East has primary reserve areas totaling 649,000 square miles, secondary areas of 131,000 square miles, and tertiary-grade areas of 195,000 square miles, a total of 975,000 square miles. Within Russian borders, as here described, are 946,000 square miles of primary areas, and adjacent Russian controlled areas amount to an additional 102,000 square miles, making a total of 1,048,000 square miles of primary areas, and another 93,000 square miles of secondary areas shown on the map, exclusive of the great Moscow-West Urals and Ob-Irkutsh basins. Though areas are used as a basis for comparison, and it is recognized that many other factors enter, the area basis offers a quick way of giving relative values, where classified into the three type groups.

Both the Middle East and Soviet Russia will require large capital for extensive development of their oil resources, together with much oil well equipment and pipelines. In Russia, the bottleneck includes both requirements, but with its great oil and other natural resources and the will to build of its large man-power resources, it requires only time to bring its oil-gas development into line with its needs. In the Middle East, American and British-Dutch, to some extent French, but principally American capital will be available—and both huge sums of money and larger amounts of equipment will be required from the United States of America for many years to come.

There can be little doubt that in the areas shown on the map Russian-owned and controlled reserves, largely undeveloped, are as great as, or greater than, Middle East reserves, and that the present probable remaining land-based oil-gas reserve in the United States is less than half of that of Russia.

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PETROLEUM EXPLORATION AND PRODUCTION IN WESTERN PACIFIC DURING WORLD WAR II[1]

LEO W. STACH[2]
Tokyo, Japan

ABSTRACT

Petroleum production in Japan proper and Formosa declined gradually during World War II because of the concentration of effort on rehabilitation and exploitation of the East Indies oil fields. Production from Japanese concessions in North Sakhalin ceased at the Katangli field in 1939 and at the Okha field in 1943. Exploration practically stopped in Japan proper and Formosa during World War II, but was maintained in Manchuria until the capitulation of Japan. Exploration in both South and North Sakhalin ceased just prior to World War II. Intensive drilling and lack of exploration in Japan proper during World War II has left Japan with practically no undrilled reserves in sight; the Natural Resources Section, General Headquarters, Supreme Commander for the Allied Powers, has assisted the Japanese Government to develop a large exploration program to find new reserves.

INTRODUCTION

Prior to her entry into World War II Japan was exploiting the oil fields of Formosa and Russian North Sakhalin in addition to those of Japan proper, situated in northwest Honshu and central Hokkaiko. Exploration outside the producing areas during this period was carried out by the Japanese in Manchuria and South Sakhalin. After Japan's entry into the war most of her effort was

TABLE I

PRODUCTION OF CRUDE OIL, CASINGHEAD GASOLINE, AND NATURAL GAS IN JAPAN PROPER AND FORMOSA FOR JAPANESE FISCAL YEARS 1941 TO 1945 (APRIL, 1941, THROUGH MARCH, 1946)*

	Japan			*Formosa*		
	Crude Oil (Barrels)	*Casinghead Gasoline (Barrels)*	*Natural Gas (1,000 Cubic Feet)*	*Crude Oil (Barrels)*	*Casinghead Gasoline (Barrels)*	*Natural Gas (1,000 Cubic Feet)*
1941	1,886,302	36,677	1,386,224	34,343	27,979	2,803,313
1942	1,611,366	40,420	1,641,205	26,940	20,864	2,539,785
1943	1,690,953	35,814	1,466,108	22,418	15,769	1,916,705
1944	1,572,311	28,758	1,516,847	21,826	17,733	2,051,329
1945	1,490,088	26,607	1,333,002		Not available	

* Production for Sakhalin is not available.

directed toward the rehabilitation and development of the rich East Indies oil fields to supply rapidly the oil needed for the maintenance of the long lines of communication necessary to accomplish her schemes of conquest in the Pacific. With her efforts concentrated on the rich prize of the readily developed East Indies fields, other areas were generally neglected.

The scale of production in areas under legitimate exploitation by Japan during World War II is indicated in Table I. It is clear that her indigenous resources

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[1] Published by permission of the chief of the Natural Resources Section, GHQ, SCAP.

[2] Head, Petroleum Branch, Mining and Geology Division, Natural Resources Section, GHQ, SCAP, APO 500, c/o Postmaster, San Francisco, California.

could supply only a very small proportion of her domestic needs and her requirements for the prosecution of the Pacific War.

Considering the long realization by Japan of her insufficiency of indigenous sources of petroleum, it is surprising to find that prospects within Japan proper and in other producing and potential areas in the Far East formerly under her control have been by no means thoroughly explored or tested.

The location of producing and prospective areas discussed in this paper is indicated in Figure 1.

JAPAN PROPER

The results of a study of petroleum production and resources in Japan proper are presented in a paper by J. David Cerkel and Jacob L. Williams[3] based on their investigation in Japan for the Natural Resources Section, a special staff section under the Supreme Commander for the Allied Powers. A short summary of the status of the petroleum producing industry in Japan proper has been compiled by C.M. Pollock, in collaboration with the writer.[4]

The policy of production of oil under Government subsidy at any cost, which prevailed in Japan during the war, resulted in over-emphasis on exploitation drilling and a virtual cessation of exploration due to the drafting of geologists to the Japanese Army and Navy Fuel Bureaus for work in the East Indies. The capitulation of Japan found the industry in a state where undrilled reserves were very small and reasonable prospects for exploration drilling, proved by geological and geophysical surveys, were negligible. Despite the emphasis on uneconomic exploitation drilling, production declined gradually throughout the war although several new fields were brought to production. The transition period of the first year of occupation, with its social and economic readjustment, resulted in a further decline in production and hampering of the exploration program.

In conformance with the S.C.A.P. policy to maximize production of indigenous resources in Japan, the Natural Resources Section is endeavoring to assist the Japanese Government in restoring the petroleum-producing industry in Japan to a position where it can operate economically without reliance on Government support. The short-range objectives are the thorough exploitation of the proved reserves, the extension of exploration drilling to prove further reserves on structures such as Yabase and Shibata where production returns are comparatively high, and the encouragement of the expanded geological and geophysical survey program to bring to light new prospects for exploratory drilling within the known producing areas. The long-range objective is the investigation of the potentialities of sedimentary basins outside the present producing areas. To coordinate and control the exploration effort available in Japan, the Japanese Ministry of Commerce and Industry has formed the Petroleum Exploration

[3] David Cerkel and J. L. Williams, "Petroleum Production and Resources of Japan," read before the Association at Los Angeles, March 26, 1947.

[4] C. M. Pollock and L. W. Stach, "Production and Resources of Petroleum in Japan," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31, No. 1 (January, 1947), pp. 156–58.

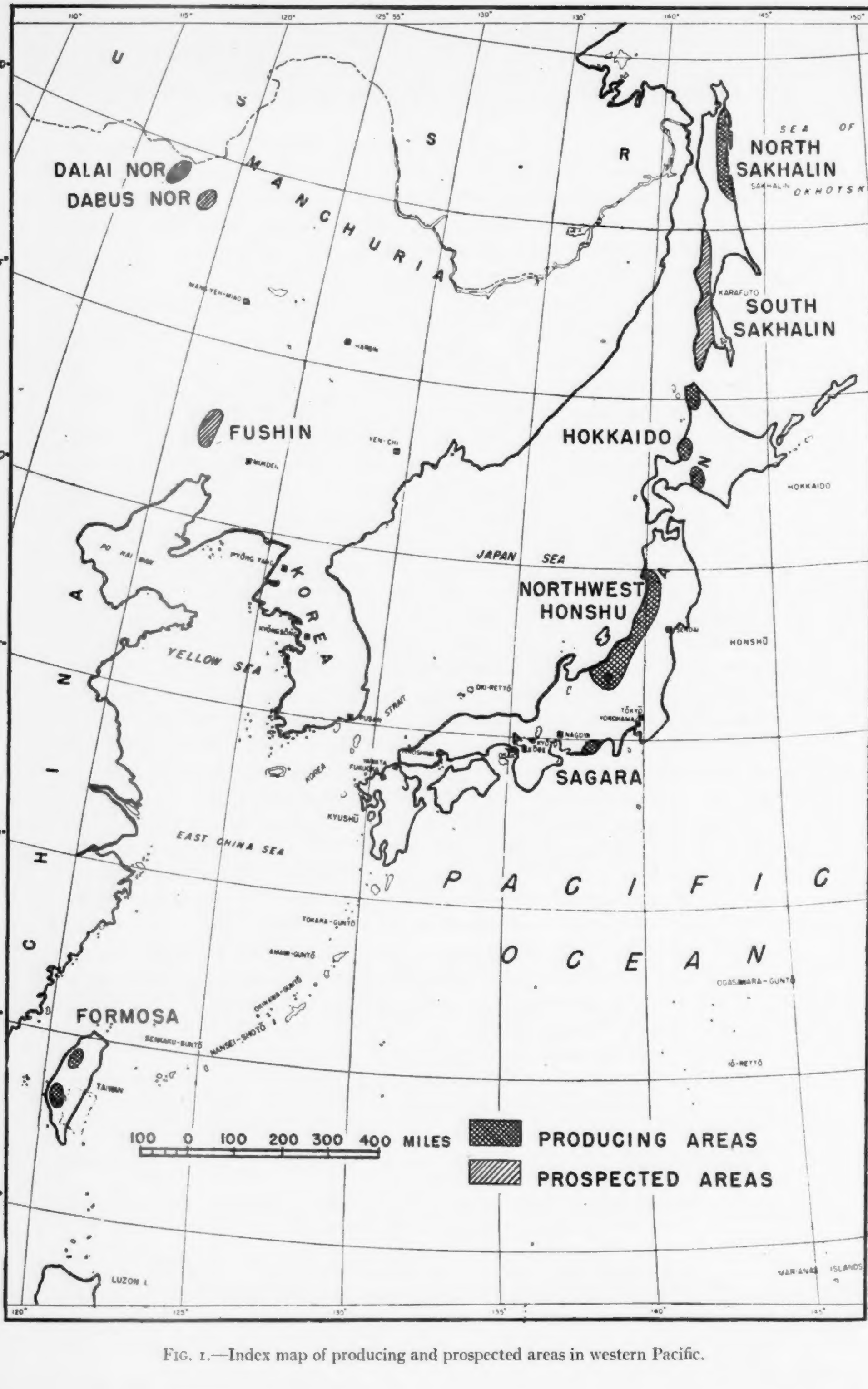


FIG. 1.—Index map of producing and prospected areas in western Pacific.

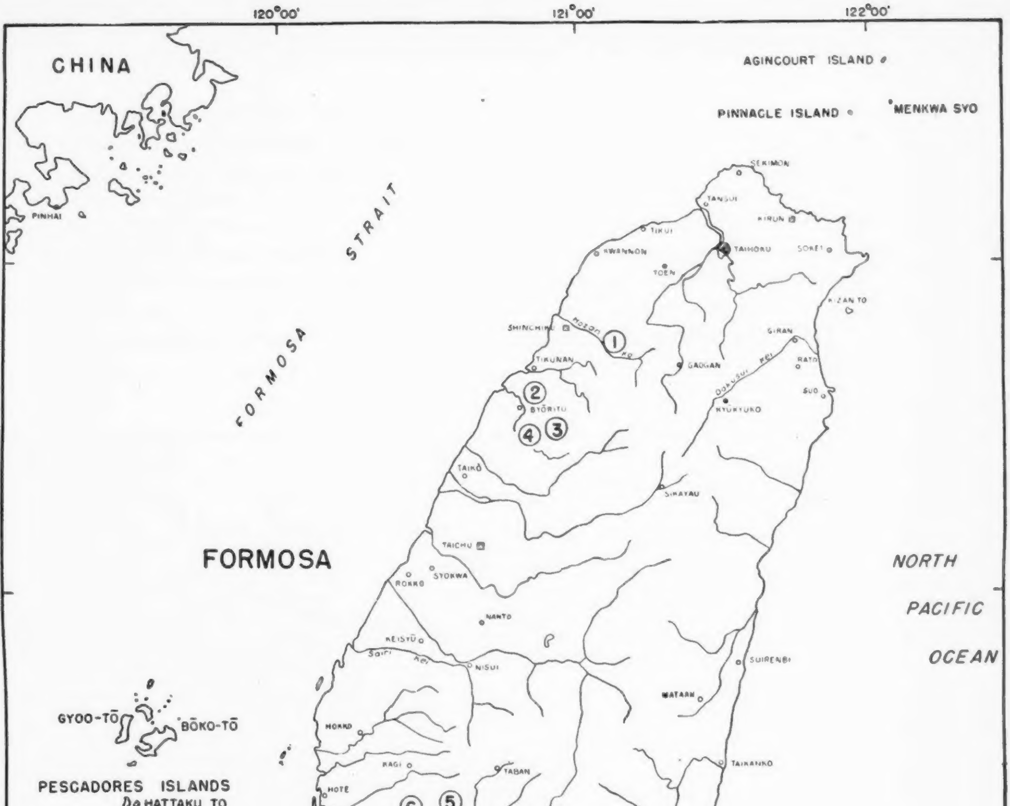


FIG. 2.—Index map of Formosa oil fields.

Advancement Committee, comprised of representatives of the Oil Section of the Ministry, the Imperial Geological Survey, producing companies, and academic institutions. A subsidy of 43 million yen, or $860,000 at the current rate, for the increase of petroleum production is under consideration for inclusion in the budget for the coming fiscal year; this subsidy will be used for paying part of the cost of drilling 50 exploration wells, the total cost of geological and geophysical surveys by parties from academic institutions, and for the purchase of additional geophysical equipment.

To accomplish the exploration objectives, the Petroleum Exploration Advancement Committee has placed the responsibility of the short-range objectives on the producing companies with some assistance from geological- and geophysical-survey parties supplied by academic institutions. The long-range objectives have been fixed as the responsibility of the Imperial Geological Survey with the assistance of parties from academic institutions. The Natural Resources Section has assisted in the development of the details of these programs by discussion and investigation of the exploration-survey projects and drilling program in the producing districts, and a reconnaissance, in company with the best of Japan's geologists, of sedimentary basins outside the present producing areas.

TABLE II
OIL FIELD DATA, FORMOSA

Name of Field	*Year of Discovery*	*Proved Area (Acres)*	*Productive Zone*			*Lowest Formation Penetrated*	*Well Status (1945)*	
			Formation	*Number of Producing Zones*	*Average Depth (Feet)*		*Total Drilled*	*Pumping Wells*
Chikuto	1934	371	Fukki sandstone Roman sandstone	2	980—shallow 4,590—deep	Roman ss.	24	0
Kinsui	1914	296	Keichikurin Shukkoko	13	1,670—shallow 11,480—deep	Shukkoko	52	?
Pakari	1937	?	Shukkoko	1	2,790	Shukkoko	6	0
Shukkoko	1904	160	Shukkoko	4	490—shallow 3,440—deep	Shukkoko	100	42
Toshikyaku	1935	89	Kanshirei	1	1,970	Kanshirei	7	1
Rokujukei	1906	49	Kanshirei	1	3,120	Kanshirei	19	0
Gyunikuzaki	1929	185	Kanshirei	2	2,290	Kanshirei	25	0
Chikutozaki	1940	7	Kanshirei	1	2,950	Kanshirei	8	2
Kosen	1920	?	Kanshirei	1	1,970	Kanshirei	5	0

FORMOSA

The oil fields of Formosa (Fig. 2) were brought under the control of the Imperial Oil Company of Japan when it was established in 1941, principally by absorbing the interests of the Nippon Oil Company. Operations continued through-

out the war on a slightly reduced scale and production declined steadily until Formosa was occupied by China after the capitulation of Japan. No new fields were discovered after Japan entered the war and only two new exploration wells were commenced.

The southern group of fields had been held in reserve by the Japanese Navy for many years and little information concerning them has been available to date. A summary of data now available from sources in Japan on fields in both north and south Formosa is contained in Table II. The fields are principally gas producers, and the production to date of crude oil and casinghead gasoline has been trifling; no estimate of reserves is available. A brief survey of the Formosa oil

(1945)	*Well Status (1945)*		*Average Daily Production (1945)*		*Cumulative Production to May 1945*		*Crude Base*	*API° Gravity of Crude*
Pumping Wells	*Gas Wells*	*Average Depth (Feet)*	*Oil (Barrels)*	*Gas (1,000 Cubic Feet)*	*Oil (Barrels)*	*Gas (1,000 Cubic Feet)*		
0	7	4,590	0	85.075	0	3,069,490		
?	25	4,100	5	2,361.872	31,890	92,037,609	Paraffine	40.4
0	0	3,280		Small amounts from 1 well, not recorded			Paraffine	31.9
42	0	2,620	27.4	291.353	1,144,834	Unknown	Paraffine (aromatic)	31.3–36.7
1	0	1,970	0	0	Probably less than 1,000	0	Paraffine	33
0	5	3,610	0	78.860	Not calculated		?	26.8
0	14	2,950	0	582.566	Not calculated			
2	0	3,280	0	0	4,800	0	?	37.3
0	0	1,800		Small quantity from one well, no records				

fields was conducted by Glen M. Ruby, of Hoover, Curtice, and Ruby, Inc., under contract to the Chinese Government late in 1945.

The oil fields are located in a belt of Tertiary sediments of Miocene and Pliocene age, more than 15,000 feet thick, on the western flank of the pre-Tertiary core which forms the high ranges of eastern Formosa. Most of the more promising areas have been mapped in detail and many test wells have been sunk, some of which penetrated 7,000 feet or more. The standard stratigraphic sequence and the stratigraphic position of oil and gas zones in northern Formosa are illustrated in Figure 3.

The trend of the structures is in general parallel with the long axis of the island. The structures near the eastern flank of the basin are generally steep, tight folds, commonly asymmetrical, and with thrust faults developed toward the east along the axial planes. Toward the west the structures become progressively more gentle and less disturbed by faulting and pass under the wide western plain of Pleistocene terrace deposits and Recent alluvium. The possibility of structures

beneath these young deposits has not been explored by geophysical methods except for a torsion-balance survey in the mud-volcano region north of Takao.

NORTH SAKHALIN

Petroleum production in Russian North Sakhalin was limited to 3 fields situated in the narrow petroliferous belt about 12 miles wide which extends 250 miles along the east coast south from Schmitt Peninsula. The known annual production from these fields is summarized in Table III.

TABLE III

ANNUAL PRODUCTION OF CRUDE PETROLEUM IN NORTH SAKHALIN (IN BARRELS)

Year*	Katangli Field		Okha Field		Ekhabi Field		Total
	Japanese	Russian	Japanese	Russian	Russian	Japanese	
1923			31,035				31,035
1934			89,519				89,519
1925	No production		83,959				83,959
1926			251,826				251,826
1927			522,316				522,316
1928	69		820,782	118,812			939,663
1929	3,132		1,262,334	181,712			1,447,178
1930	8,045	No production	1,299,564	670,935			1,978,544
1931	13,266		1,260,654	936,506			2,210,426
1932	7,774		1,258,491	1,278,964	No production	No production	2,545,229
1933	16,096		1,307,748	1,372,616			2,696,460
1934	20,071		1,094,655	1,691,312			2,806,038
1935	28,022		1,105,637	1,672,441			2,806,100
1936	167,037		1,049,568	2,151,180			3,367,785
1937	135,317		881,745	2,488,047			3,505,109
1938	171,333	100,370	687,679	2,522,290			3,481,672
1939	63,793	133,832	574,170	3,319,724†			4,091,519†
1940			387,935				
1941	No production	Not available	295,623	Not available	Not available		Not available
1942			384,315				
1943			114,981				

* Japanese fiscal year, April through March.
† Estimate.

In 1925 the Japanese North Sakhalin Oil Company began to exploit the oil fields under the terms of a 45-year contract with Russia. Exploitation leases were laid out on a checkerboard system of alternating Russian and Japanese leases, and exploration rights were granted to the Japanese over large blocks of territory. Labor troubles and strained political relations with Russia since 1936 resulted in a marked decline in production on the Japanese concessions and a reduction in drilling and exploration activity. Production on the Japanese concessions at the Katangli oil field ceased in 1939 and at the Okha field in 1943. The strained relations between Russia and Japan resulted in the cessation of operations by the Japanese and their evacuation in November, 1943. Finally, the 45-year contract was dissolved by Russia on March 31, 1944, with the compensatory payment of 5 million rubles (about $950,000) and an agreement to supply Japan 50,000 metric tons of crude oil per year on a trade basis for 5 years after the conclusion of the war.

It is not known whether production is being maintained by Russia. The limited storage facilities available at site and refining capacity sufficient only for local consumption within the oil fields suggest that the fields are currently inoperative unless the crude oil is being shipped out.

The geology and stratigraphy of the area are illustrated in Figures 4 and 5. The present oil-producing beds are in Pliocene formations in the upper part of a Neogene sequence nearly 30,000 feet thick. This great thickness of mainly marine sediments was deposited without any major stratigraphic break. Orogeny at the close of the Tertiary resulted in the development of a series of anticlines generally

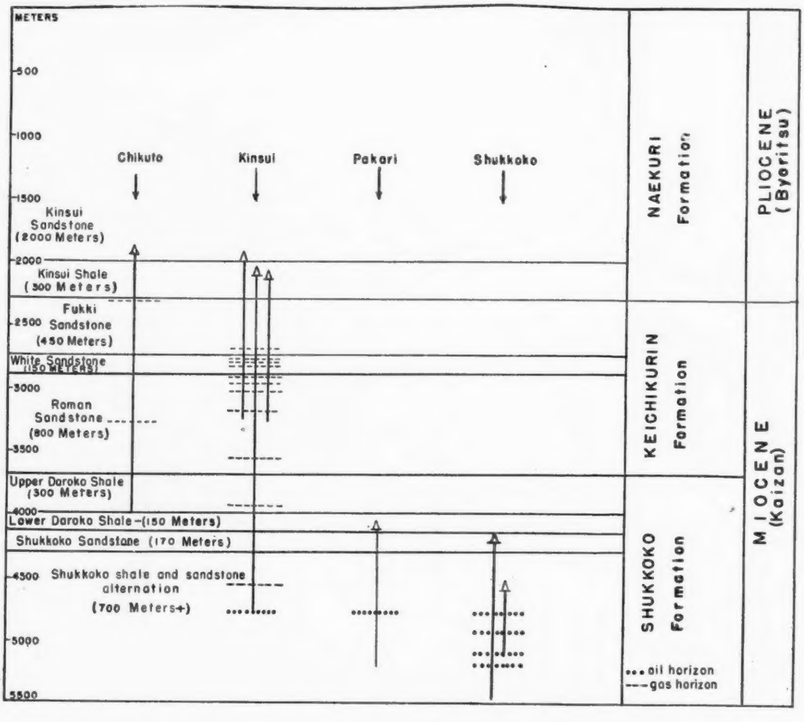
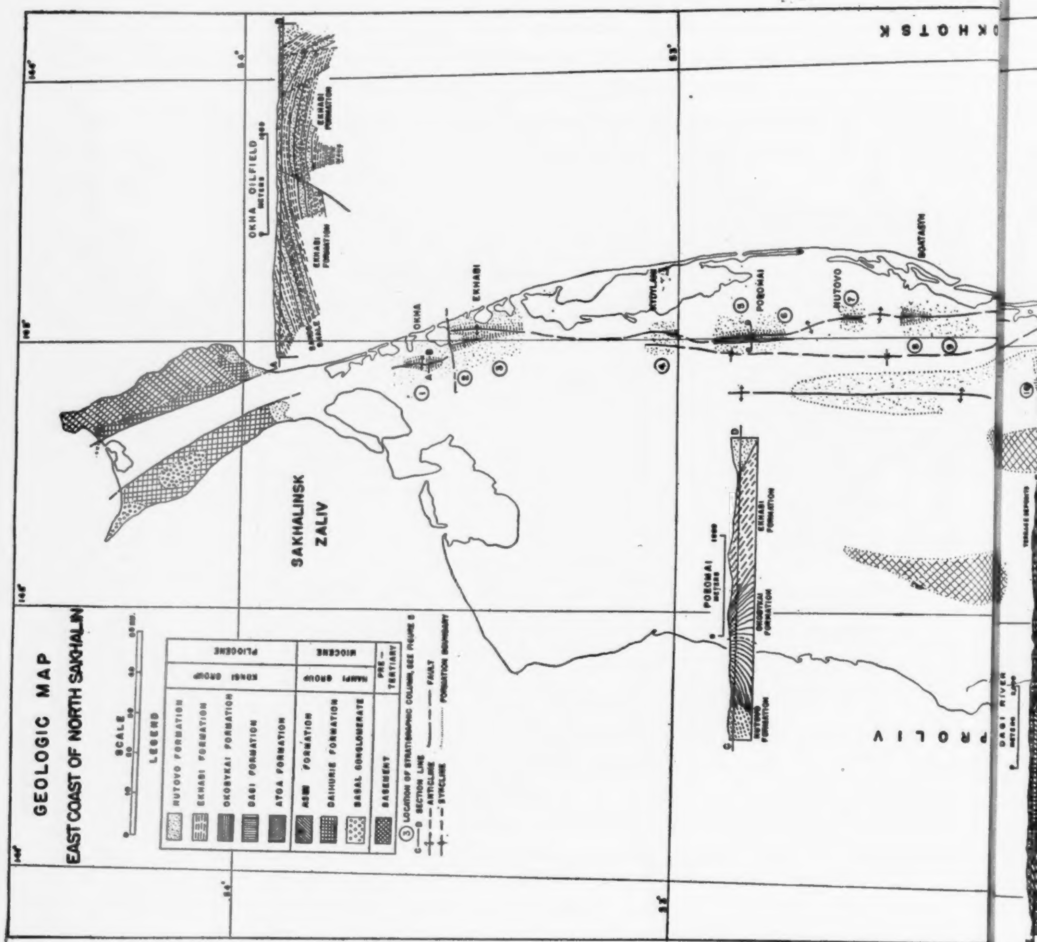


FIG. 3.—Standard stratigraphic sequence in oil fields of northern Formosa and stratigraphic position of oil and gas zones. Penetration by wells is indicated.

parallel with the present trend of the coastline. Most of the recognized fields are on local highs along the crest of what is regarded as one anticline with a total length of about 150 miles. The folds are generally asymmetrical with the axial planes dipping west. Broad flat-topped domes were the first targets for exploitation, but some testing of the steeper, pinched structures has been done with generally poor results.

Exploitation by the Japanese has been confined to shallow zones and no deep tests have been attempted. A summary of available data on the Japanese parts of the two fields exploited by them is contained in Table IV. In addition to the Russian leases exploited in these fields, oil was also produced by Russia from the


GEOLOGIC MAP
EAST COAST OF NORTH SAKHALIN
SCALE
LEGEND
NUTOVO FORMATION
EKHABI FORMATION
OKOBYKAI FORMATION
DAGI FORMATION
ATOA FORMATION
ASMI FORMATION
DAIHURIE FORMATION
BASAL CONGLOMERATE
BASEMENT
KONGI GROUP
PLIOCENE
NAMPI GROUP
MIOCENE
PRE-TERTIARY
LOCATION OF STRATIGRAPHIC COLUMN, SEE FIGURE 5
SECTION LINE
ANTICLINE
SYNCLINE
FAULT
FORMATION BOUNDARY
SAKHALINSK
ZALIV
OKHA OILFIELD
METERS
EKHABI FORMATION
OKHA
EKHABI
KYDYLANI
POGOMAI
NUTOVO
BOATASYN
POGOMAI
METERS
OKOBYKAI FORMATION
EKHABI FORMATION
NUTOVO FORMATION
DAGI RIVER
METERS
OKHOTSK
PROLIV

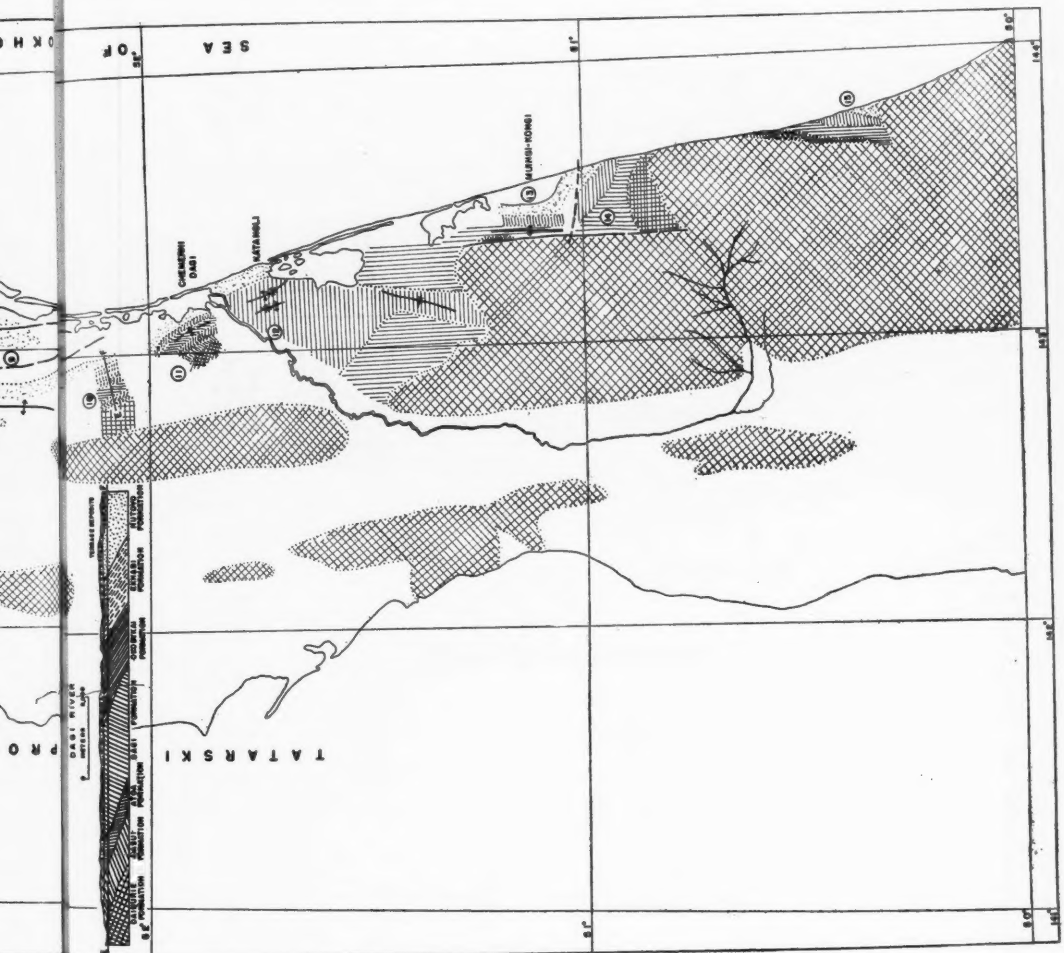


FIG. 4.—Geologic map of east coast of North Sakhalin.

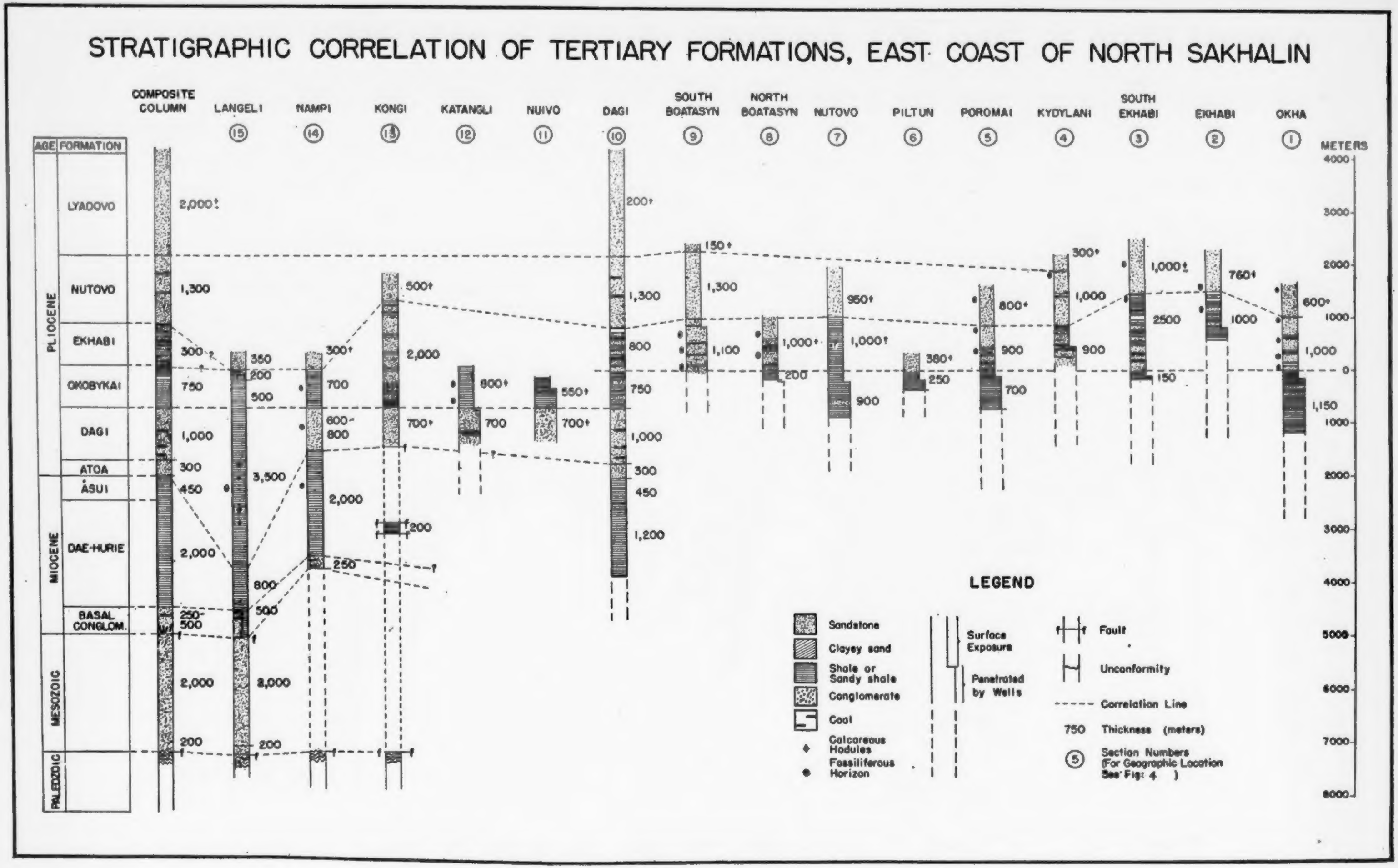


FIG. 5. Stratigraphic correlation of Tertiary formations of east coast of North Sakhalin.

Ekhabi field. Many other areas were surveyed in detail by the Japanese and some were tested by drilling. It is the general opinion of Japanese geologists that the potentialities of North Sakhalin are great. An estimate of reserves by T. Niiya, former chief geologist of North Sakhalin Oil Company, based on the results of the geological work by the company, is contained in Table V. The estimates include both the Russian and former Japanese concessions. These estimates, however, do not take into account the possibilities of production from potential zones stratigraphically lower than those already tested and in production, and the possibility of production from structures which may underlie the coastal lagoon belt. No geophysical prospecting has yet been attempted in North Sakhalin.

TABLE IV

STATISTICS OF JAPANESE CONCESSIONS IN EXPLOITED OIL FIELDS IN NORTH SAKHALIN

		Okha Field	*Katangli Field*
Year of discovery		1921	1921
Proved area		242 acres	329 acres
Producing zone	Formation	Ekhabi	Okobykai
	Total thickness of producing zones*	879 feet	115 feet
	Number of producing zones	11	2
	Depth to top zone	98–230 feet	98–525 feet
Lowest formation reached		Penetrated 1,150 feet of Okobykai formation	Penetrated 1,640 feet of Dagi formation
Well status 1943	Total wells drilled	258	43
	Pumping wells	215	38
	Flowing wells	0	0
	Abandoned wells	43	5
	Average depth	760 feet	407 feet
	Deepest well	3,510 feet	1,970 feet
Peak average daily production		3,585 barrels (1933)	465 barrels (1938)
Cumulative production		14,728,538 barrels (to 1943)	633,956 barrels (to 1939)
Proved reserves†		65,533,000 barrels	49,522,500 barrels
Crude base		Asphaltic	Asphaltic
API gravity of crude		20.6	19.0

* Very few wells have been drilled to the deeper zones; most of the oil was produced from the four shallowest zones.
† Total volume of oil remaining in reservoirs; reservoir conditions suggest high recoveries will be obtained.

SOUTH SAKHALIN

No oil or natural gas has been produced commercially in South Sakhalin. Geological exploration for oil was carried out sporadically in South Sakhalin since 1920 by geologists on the staff of the Mining Bureau of the Government of South Sakhalin, located at Toyohara. Visiting geologists from Japan also con-

FIG. 5. Stratigraphic correlation of Tertiary formations of east coast of North Sakhalin.

tributed to the exploration. The Nippon Oil Company carried out test drilling under contract to the Mining Bureau. The disappointing results of this program led to suspension of the efforts just prior to Japan's entry into World War II. As a result of the exploration work, a geological map, scale 1:500,000, and explanatory text were published in 1939. Following the capitulation of Japan, South Sakhalin was taken over by the U.S.S.R. under the terms of the Yalta agreement.

Paleozoic basement rocks are found in both the southeastern and northeastern peninsulas of South Sakhalin (Fig. 6). The older Paleozoic group which crops out east of Toyohara in the southeastern peninsula consists mainly of sericite schist, chlorite schist, graphite schist, and pyroxenite. The younger Paleozoic

TABLE V

ESTIMATED OIL RESERVES IN NORTH SAKHALIN

Field	*Estimated Area (Acres)*	*Oil Reserves* (Unit—1,000 Barrels)*		
		Proved	*Probable*	*Possible*
Okha	439	160,000		
North Okha	211		46,800	
Ekhabi	148		35,000	
West Ekhabi	371	87,431		
North Ekhabi	173		40,570	
Poromai	198		45,288	
Piltun	86			8,680
Nutovo	334		63,529	
North Boatasyn	185			17,612
Chaivo	99		9,435	
Nuivo	111			11,322
Katangli	593	122,026		
North Katangli	185			30,821
Total	3,133	369,457	240,622	68,435

* Total volume of oil in reservoirs; reservoir conditions in known fields suggest high recoveries will be obtained.

rocks, regarded as Permo-Carboniferous in age, consist largely of graywacke, slate, quartzite, phyllite, and limestone; they occupy the main part of the southeastern peninsula flanking the older Paleozoic group on the east and form the base of the northeastern peninsula. The Paleozoic complex is probably an extension of the Hidaka mountainland complex, which forms the backbone of Hokkaido.

On both the eastern and western flanks of the now discontinuous meridional Paleozoic belt a considerable thickness of sediments, ranging in age from Lower Cretaceous through the Tertiary, was deposited.

Cretaceous (Neocomian to Senonian) sedimentary rocks, both terrestrial and marine, form the long axis of South Sakhalin (Fig. 6).

Early Tertiary orogeny caused uplift and folding of these Cretaceous basins along north-south trends, so that the history of deposition of the Tertiary sediments on the east and west flanks of each of the incipient Cretaceous orogens differs somewhat, particularly in its earlier phases.

The stratigraphy of the Tertiary formations on the east and west flanks of the western Cretaceous belt is summarized in the stratigraphic columns shown in

Figure 7. Following the great orogeny at the close of the Tertiary which was mainly responsible for the folding and deformation of the Tertiary sediments, andesites were extruded through the Tertiary sediments on the western flank of

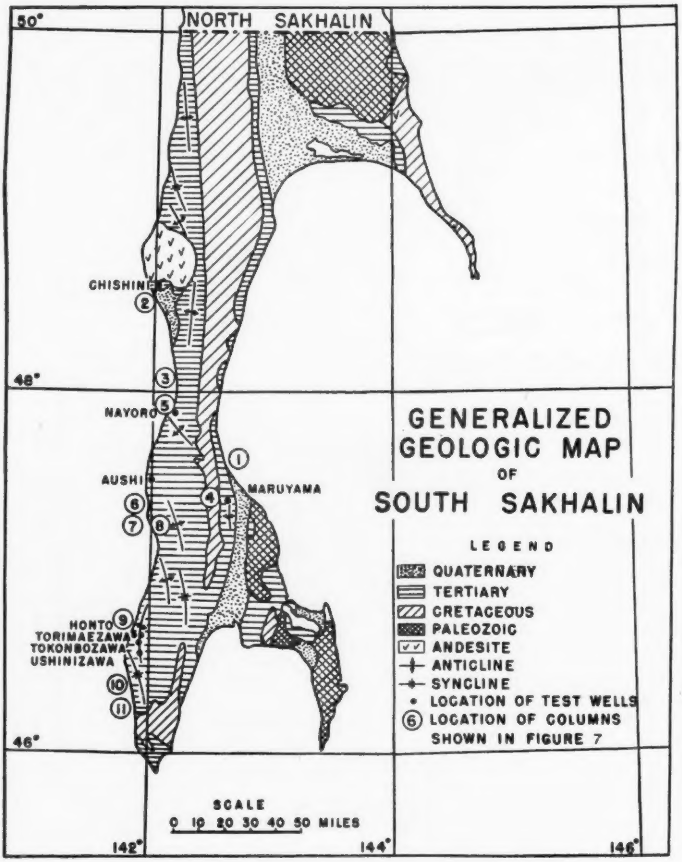


FIG. 6.—Generalized geologic map of South Sakhalin.

the western Cretaceous belt and through the Cretaceous of the northeastern peninsula.

The relationship between the history and type of Tertiary sedimentation in the northwestern basin of Hokkaido on the western flank of the Hidaka mountainland and that of the western flank of the western Cretaceous belt in South Sakhalin is indicated in Figure 7. The close connection between these Tertiary

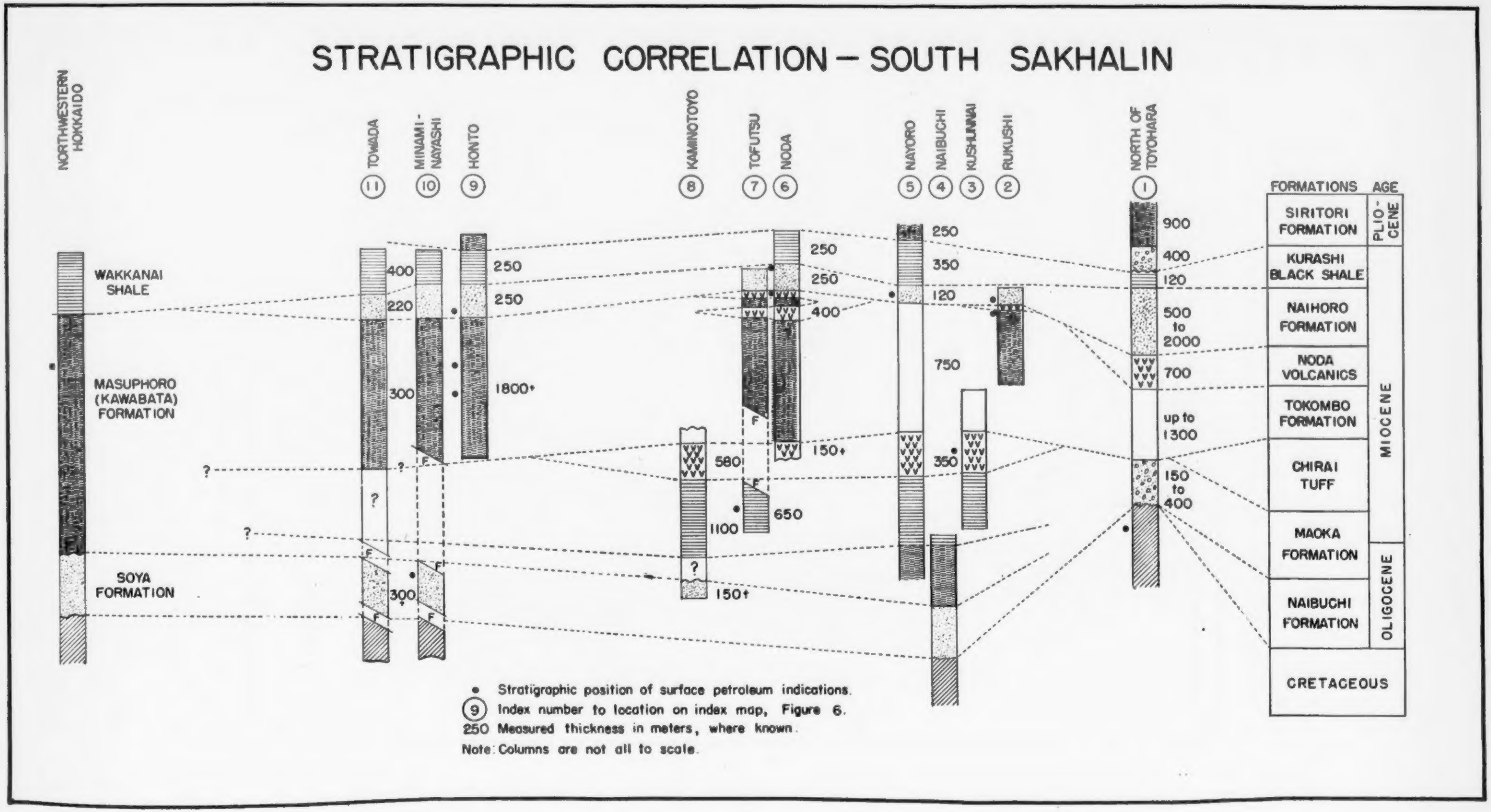


FIG. 7.—Stratigraphic correlation of Tertiary formations in South Sakhalin and northwest Hokkaido.

TABLE VI

JAPANESE EXPLORATION WELLS IN SOUTH SAKHALIN

Locality	*Well No.**	*Date Spudded*	*Depth Drilled (Feet)*	*Oil and Gas Showings*	*Formations Containing Oil and Gas Indications*	*Formations Penetrated*
Chishini	C.1	Feb. 1938	1,980	No showings		Naihoro
Chishini	C.2	Feb. 1939	2,130	No showings		Naihoro
Chishini	C.3	Nov. 1939	993	Small gas showings at 130 meters (426± feet)	Naihoro ?	
Nayoro	R.1	Oct. 1932	4,760	Small gas showings at 700 to 950 meters (2,296± to 3,116± feet)		Kurashi, Naihoro, Tojyo
Nayoro	R.2	Oct. 1933	2,553	Faint gas showings at shallow depths	Naihoro ?	Naihoro, Tojyo
Aushi	K.1	—	656			Naihoro
Aushi	K.2	—	656			Naihoro
Honto	R.1	July 1929	3,715	Gas showing at 900 meters (2,952± feet)	Tokombo	Tokombo
Torimaezawa	C.1	—	—		—	—
Torimaezawa	C.2	Dec. 1930	4,602	Water at 250 to 470 (820± to 1,541± feet). Small gas showings below 600 meters (1,968± feet)	Tokombo	Tokombo, Chirai tuff
Tokombozawa	C.1	Oct. 1923	1,622	Oil showing at 273 meters (895± feet)	Tokombo	Tokombo
Ushinizawa	C.1	Nov. 1935	4,434	Small gas and 1,800 kiloliters per day of water at 200 meters (656± feet). 2,700 kiloliters per day of water at 400 meters (1,312± feet). Small gas and 1,460 kiloliters per day of water at 687 meters (2,253± feet)	Tokombo	Tokombo
Ushinizawa	R.1	Oct. 1938	4,428	Small oil showing at 1,016 meters (3,332± feet)	Tokombo	Tokombo
Ushinizawa	R.2	Oct. 1939	3,844	Oil and gas showings at 267, 384, and 615 to 642 meters (875±, 1,259± and 2,017± to 2,105± feet)	Tokombo	Tokombo Tokombo
Ushinizawa	R.3	Aug. 1940	3,608	No oil; water 2.5 to 1 kiloliter per day	Tokombo	Tokombo
Maruyama	R.1	Oct. 1931	5,040	No showings	Siritori	Maruyama sandy shale and conglomerate
Maruyama	R.2	Sept. 1934	5,275	No showings	Siritori	Maruyama sandy shale and conglomerate

* C, cable-tool; R, rotary; K, Kazusa-type well.

basins is further suggested by a study of the trends of the gravitational anomalies in northern Hokkaido.

The thin section of Tertiary sedimentary rocks flanking the Paleozoic and Cretaceous belt extending north from the northeastern peninsula has a small areal extent and the structure is generally unfavorable for oil accumulation. In Russian North Sakhalin, however, the Tertiary sediments of the east flank open into a deep embayment in which the oil fields have been developed.

Tertiary sediments occupy a narrow strip on the east flank of the western Cretaceous belt dipping regularly eastward except at the southern end, north of

Toyohara, where a few small anticlines have been developed in the narrow area between the western Cretaceous belt and the older Paleozoic mass. Oil indications are known near Maruyama in the Pliocene but two test wells at the northern end of the Maruyama anticline yielded no traces of oil or gas.

The Tertiary deposits of South Sakhalin are best developed on the western side of the western Cretaceous belt. The total thickness of the formations ranges from 3,500 to 11,000 meters (11,480± to 36,080 ±feet). The Tertiary formations are folded into a series of commonly gentle *en échelon* anticlines trending from north to northwest. Surface oil and gas indications are commonly found in most of the Tertiary sedimentary formations and gas seepages are known in two localities in the Cretaceous. Several of the Tertiary structures were drilled but no commercial accumulations have been located, although numerous oil and gas showings were encountered; locations of the test borings are shown in Figure 6. A summary of the results of the individual test wells is contained in Table VI.

These tests are all restricted to the upper half of the Miocene section although surface oil and gas indications are known in formations lower in the Tertiary sequence and in the Cretaceous. The older Tertiary and Cretaceous formations, which are known in outcrop near the eastern margins of the embayment to be generally of shallow-marine or fresh-water origin, could conceivably be represented by a deeper-water facies at depth farther west in the basin. The possibility of the development of source rocks in these lower formations away from the flanks of the basin can not therefore be ignored. The possibilities of discovering commercial accumulations of oil have by no means been exhausted in South Sakhalin and potentialities worthy of further exploration still exist.

MANCHURIA

Reports of gushers brought in near Fushin just prior to the outbreak of war are found to have been grossly exaggerated and no oil has been produced commercially in any of the prospected areas in Manchuria.

The oil possibilities of Manchuria were not considered seriously prior to 1931 because of the lack of oil indications and possible source rocks in the Paleozoic and because of the continental and fresh-water facies of the Mesozoic and Tertiary rocks. Oil indications were known for many years, but most of these were the result of natural distillation by igneous intrusions through the widespread Mesozoic oil shales. However, the discovery of black bitumen in amygdaloidal basalts in the Dalai Nor area in 1918 led to sporadic investigation since the bitumen was regarded as derived from crude petroleum. From 1932 to 1934 the Kwantung Army conducted a mineral-resources survey during which the occurrence of bitumen at Dalai Nor was examined in more detail and diamond-drill tests were made. In February, 1934, the Kwantung Army established the Manchuria Petroleum Company, the primary function of which was the refining of imported crude oil. The company was also charged with the responsibility of investigating the possibilities of indigenous production. Attention was directed

toward the Mesozoic rocks because of their great thickness, the occurrence of crude-oil residues at Dalai Nor, and because some oil had been produced in the Mesozoic in Shensi and Szechwan provinces of China.

The Manchuria Petroleum Company carried on the investigation at Dalai Nor until 1939 by means of geological, torsion-balance, and seismic surveys and exploratory drilling. The salt-lake area of Dabus Nor, about 50 miles south of Dalai Nor, was originally studied by the Kwantung Army in 1934. The Manchuria Petroleum Company and South Manchuria Railway Company conducted a geological survey of this area in 1935, and in 1939 the Manchuria Mining Exploration Company conducted a torsion-balance survey. In the course of exploratory drilling for coal in the Fushin area (not to be confused with the coal and oil-shale area of Fushun, east of Mukden) by the Fushin Coal Mining Company (formerly the Manchuria Coal Mining Company) between 1933 and 1937, numerous oil indications were found in the cores. As a result, the Manchuria Petroleum Company conducted a detailed geological survey from 1939 to 1942 and made a torsion-balance survey in conjunction with the Manchuria Mining Exploration Company in 1938 and 1939. Exploratory drilling was commenced in 1939 and continued through the war until 1945. It is presumed that the drilling program ceased with the capitulation of Japan. The general location of the three prospected areas is shown in Figure 1.

The trifling production in Manchuria came from the Tongkan-kaning culmination of the Ching-ho-meng anticline in the Fushin area. The total production to date from 7 wells is less than 410 barrels.

The area surveyed on the northwestern shore of Dalai Nor consists of a pre-middle Jurassic igneous group comprising trachy-andesitic basalt with amygdules containing black bitumen, trachytes, liparite, and pyroxene andesite overlain unconformably by middle Jurassic sedimentary rocks consisting of a basal conglomerate about 150 feet thick and more than 2,500 feet of gray shale with thin sand and gravel intercalations.

The middle Jurassic sedimentary rocks are best developed on the eastern downthrown side of a north-trending normal fault close to the northwest shore of the lake (Fig. 8). The porous basalt containing bitumen is found on the upthrown side of the fault.

The middle Jurassic sedimentary rocks form a gentle monocline dipping east and underlain at depth by the pre-middle Jurassic igneous group.

Drilling through the basalts on the upthrown block has shown that several successive flows each contain bitumen in the amygdules of the lower part of each flow. The bitumen is found enclosed even in the chalcedonic infillings found in some of the amygdules. It seems clear that the original crude petroleum must have been brought up with the basalt when it was extruded. This led to the assumption of a petroliferous formation below the igneous group, but its presence has not been confirmed by drilling.

Pebbles of the amygdaloidal basalt containing bitumen are also found in

the middle Jurassic basal conglomerate together with pieces of free bitumen as large as 2 inches in diameter. Some very viscous oil was also discovered at depths of about 400 feet in sand intercalations within the gray shale. The oil was too viscous to be pumped and a hand-dug shaft to examine these sands was sunk to 160 feet before the outbreak of war stopped operations. This oil is believed to have migrated through faults in the igneous group from the assumed underlying petroliferous formation, or to have migrated updip from source rocks in the middle Jurassic farther east (Fig. 8).

Between 1933 and 1941 two rotary wells were drilled and 31 diamond-drill

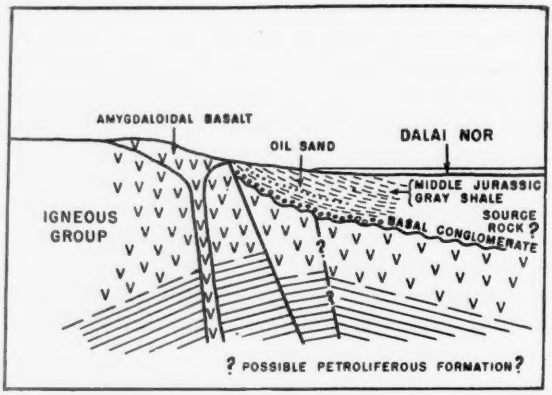


FIG. 8.—Diagrammatic west-east section, Dalai Nor, northwest Manchuria.

tests were made, but at the close of 1941 the rotary equipment was sent to the East Indies and the diamond drills to Fushin.

Attention was drawn to the Dabus Nor area because of three lakes with fairly high salt content. No bedrock outcrops are known in this area of desert and steppe. Gravity survey by torsion balance produced nothing to indicate the presence of rock salt and a shallow well drilled in the vicinity met with liparite 150 feet below the fluviatile and eolian surface deposits. It was therefore concluded that the salt concentration in the lakes was due to evaporation in closed basins and was not similar to the petroleum and brine associations in China.

The area prospected in the vicinity of Fushin occupies a graben flanked by mountain ranges of the Sinian (pre-Cambrian) system. The floor of the graben is occupied by both volcanic and sedimentary rocks of Mesozoic age with a total thickness of more than 12,000 feet. Basalt and tuff form the base of the section and nearly 3,000 feet of black shale is developed in the lower part of the sequence; the coal-bearing formation, of late Jurassic age, is found near the top of the section.

Oil indications have been discovered in three formations within the Jurassic, and the black shales of the lower part of the sequence are a possible source rock. Seven structures with northeast-southwest trend have been located by geological survey in the graben. All structures are symmetrical anticlines with flanks dipping from 10° to 30°, but the structures are cut by transverse normal faults which divide some of them into several blocks.

The Toholo anticline, three culminations on the Ching-ho-meng anticline, and two culminations on the Chiang-chang anticline have been tested by drilling to depths ranging from 1,600 to nearly 6,500 feet. This drilling program, comprising 18 rotary wells, 17 cable-tool wells, and 47 diamond-drill wells, was executed between 1939 and 1945. Apart from the small production noted the results met with no success.

PHILIPPINES

The extensive program of exploration for oil carried out under the direction of Grant W. Corby of Los Angeles for the National Development Company was interrupted by the Japanese invasion of the Philippines. The drilling equipment at the Far East Oil Development Company's deep test in Cebu was destroyed to prevent its use by the Japanese.

No continuation of the exploration or drilling program was attempted by the Japanese during the war. Samples collected by the exploration survey were preserved intact in the National Development Company's store in Manila, but samples and equipment stored in the Bureau of Mines were completely destroyed during the recapture of Manila early in 1945.

EAST INDIES

Production of oil in the East Indies during the Japanese occupation was under the jurisdiction of the Japanese Army and Navy Fuel Bureaus. The Army Fuel Bureau controlled all fields and refineries except those of Dutch Borneo, Ceram, and Dutch New Guinea. Production statistics and geological reports were forwarded to Army and Navy Headquarters in Japan, but all these documents were destroyed by fire on August 14, 1945, at the direction of the War Ministry. Practically no reliable information is therefore available in Japan except what can be ascertained from the personal recollections of Japanese who were formerly employed by the Army and Navy Fuel Bureaus.

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DEVONIAN SYSTEM IN CENTRAL AND NORTHWESTERN MONTANA[1]

LAURENCE L. SLOSS[2] AND WILSON M. LAIRD[3]
Evanston, Illinois, and Grand Forks, North Dakota

ABSTRACT

The Devonian strata of central and northwestern Montana are confined to an Upper Devonian age. In central Montana these rocks are divided, in order of increasing age, into the Three Forks formation, predominantly shale; the Jefferson formation, composed of an upper dolomite member, including some anhydrite or evaporite-solution breccia, and a lower dense limestone member; and an unnamed basal unit of shale and shaly dolomite which bears a transgressive relationship to the underlying Ordovician and Cambrian. In northwestern Montana these terms are not applicable and the Devonian is divided, in descending order, into arbitrary units A, B, and C. Unit A is dolomite and anhydrite, or evaporite-solution breccia, unit B is dense limestone, and unit C is a red shale and shaly dolomite sequence resting on the channeled surface of the Upper Cambrian.

Oil is produced from the Devonian of south-central Alberta and gas has been encountered in it in Montana. Petroleum possibilities appear to be confined to the dolomites of the Jefferson formation and unit A, and it is suggested that these possibilities may have been enhanced by favorable depositional environments and post-depositional effects.

INTRODUCTION

PURPOSE

Devonian stratigraphy in Montana has received little detailed attention since the work of Peale (1893, pp. 25–32) and Weed (1900, pp. 287–89). In order to lay a foundation for the more complete understanding of the petroleum possibilities of Devonian strata in Montana, the writers undertook a study of these rocks in all areas of Montana where they are exposed or where subsurface data are available, excepting the extreme southern and southwestern parts of the state. The investigation was carried out as part of the United States Geological Survey's oil and gas investigations, in cooperation with the Montana Bureau of Mines and Geology. Preliminary reports have been published (Sloss and Laird, 1945 and 1946), and reference is made to these reports for certain details not repeated in the present paper.

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[2] Department of geology, Northwestern University, Evanston, Illinois.

[3] North Dakota Geological Survey, Grand Forks, North Dakota. The writers are indebted to C. E. Erdmann, L. S. Gardner, and T. A. Hendricks of the United States Geological Survey for valuable aid and suggestions during the field and laboratory studies. E. S. Perry and U. Sahinen of the Montana Bureau of Mines and Geology rendered important services, the former during preparation of the manuscript and during intensive discussions leading to the development of the writers' concept of the problem and the latter in preparation of part of the illustrative material. C. F. Deiss, formerly of the Montana State University, aided materially in expediting field work in the remote areas of northwestern Montana by drawing on his long experience in that part of the state to indicate the most useful exposures and their most practical approach. Numerous oil-company geologists, particularly John E. Blixt of The Texas Company, Ian Cook of the British American Oil Company, and Max Littlefield of the Gulf Oil Corporation, supplied many of the subsurface samples and data on which this report is based. Grateful acknowledgment is due H. D. Miser, A. A. Baker, and others of the staff of the United States Geological Survey for critical reading and revision of the manuscript.

METHODS

The most of the stratigraphic sections were measured with a Jacob's staff applied directly across the bedding and a composite sample was collected for each 5 feet of stratigraphic interval. Where the exposures were inadequate or the attitude of the strata unsuitable for this method, measurements were made by tape or alidade traverse, and samples were collected from each lithologic subdivision. In the laboratory, samples were crushed, washed, and examined under the binocular microscope for comparison with the available samples from the wells in the area that penetrated the Devonian.

DISTRIBUTION

Devonian strata are present everywhere in Montana, excepting where removed by post-Laramide erosion, and in the southeastern quarter of the state. The eastern and southern margin of distribution lies east of the Beartooth Mountains, south of the Big Snowy Mountains, and north of the southern end of the Baker-Glendive (Cedar Creek) anticline. Insufficient subsurface control makes it impossible to determine accurately the southeastern margin of distribution, but it appears to have been controlled by the ancient positive element of Siouxia, which was active throughout much of Paleozoic time.

The thickness and character of the Devonian rocks in Montana indicate a marked departure from the normal Paleozoic pattern (Perry and Sloss, 1943, Fig. 2), which includes a thick geosynclinal section near the western border of the state, thinning or absence on the Sweetgrass arch positive element in the north-central area, and eastward thickening into the Williston basin.

During late Devonian time, the Sweetgrass arch remained inactive and was, for part of the time, the site of an evaporite basin. This basin was flanked on the south in central Montana by a minor east-west positive element which occupied the approximate position of the Little Belt-Big Snowy-Porcupine trend of the Laramide uplift. This east-west positive element also coincides with a subsiding axis of pre-Cambrian, Cambrian, and Mississippian time. Devonian sedimentation in Montana is thus divided into two basins of sedimentation; a minor one north of Siouxia and south of the minor east-west positive area, and a much larger basin in northern Montana extending into Alberta and beyond.

STRATIGRAPHIC RELATIONS

Over most of the area of Devonian distribution in Montana, Upper Devonian strata lie disconformably above Upper Cambrian strata. In the mountains of the northwestern part of the state the contact is clearly marked between basal Devonian shales and a channeled surface with an observed relief of 20–30 feet cut in Cambrian dolomites. In central Montana, however, shales, mudstones, and argillaceous dolomites assigned to the Devonian are apparently transitional with beds lithologically like the Upper Cambrian Dry Creek shale. Previously, Weed (1899, pp. 287–89) and Deiss (1936, pp. 1336–37) assigned all of the shales to the

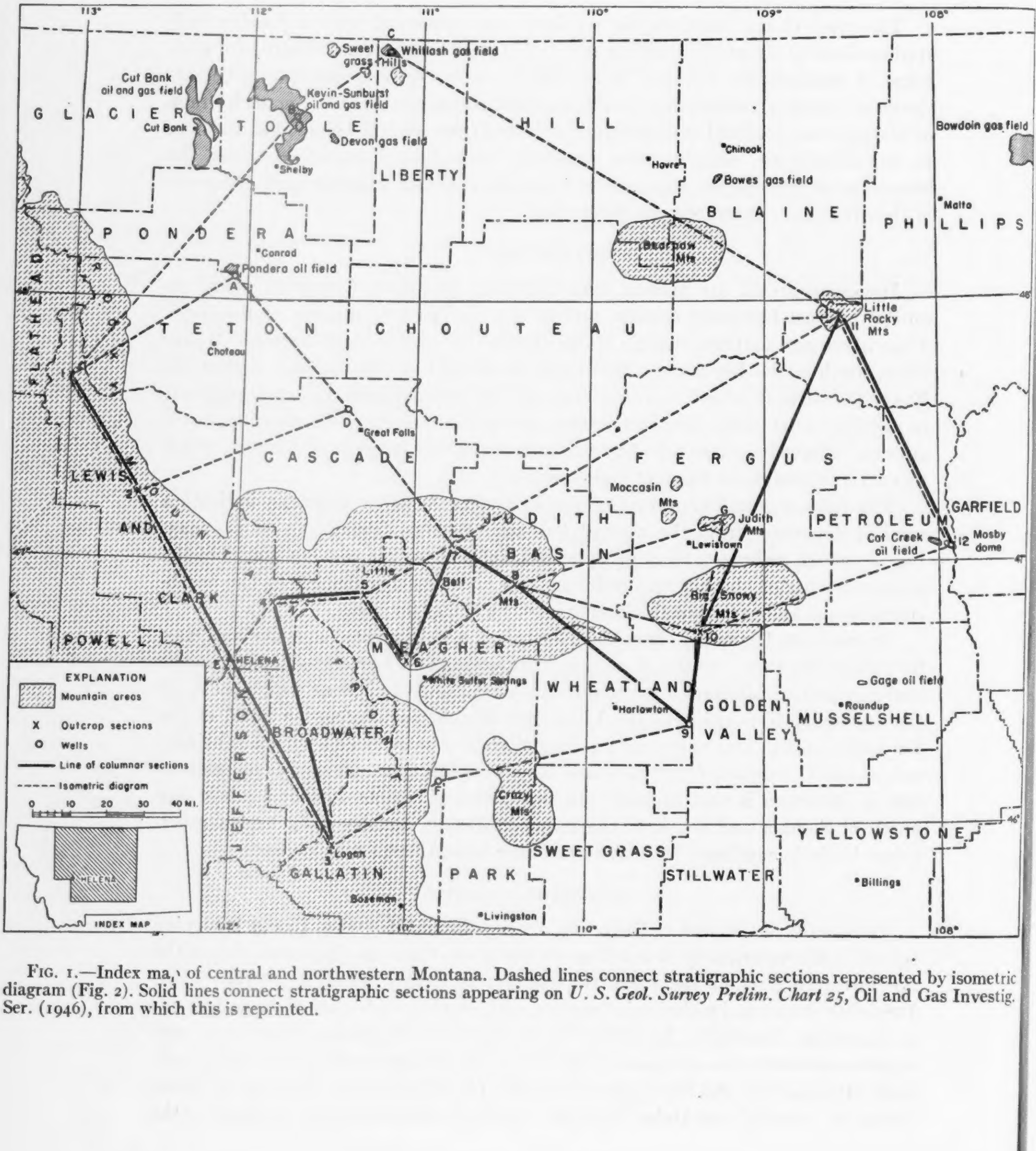

FIG. 1.—Index ma, of central and northwestern Montana. Dashed lines connect stratigraphic sections represented by isometric diagram (Fig. 2). Solid lines connect stratigraphic sections appearing on *U. S. Geol. Survey Prelim. Chart 25*, Oil and Gas Investig. Ser. (1946), from which this is reprinted.

Cambrian, although Deiss recognized the difficulty of separating them from the Devonian. The writers believe that a variable proportion of the shale previously placed in the Cambrian is Devonian in age because of (a) the lithologic similarity of shale of known Devonian age at the same stratigraphic position in the northwestern area, (b) the upward transition of the apparently Cambrian shale into beds bearing Devonian fossils, and (c) the occurrence of similar strata at the base of the Devonian in areas where Ordovician rocks separate the Cambrian and the Devonian.

Closely spaced measurements along the strike of the Cambrian-Devonian contact reveal marked variations in the proportional thicknesses of strata assigned to the Dry Creek shale (Cambrian) and to the basal Devonian. This variation suggests a surface of considerable relief at the top of the Cambrian indicating that the basal Devonian shales are thickest where the Cambrian was more deeply cut by erosion. In the Little Rocky and Beartooth uplifts and in wells adjacent to them, the Devonian rests disconformably on Upper Ordovician dolomites, and the contact is marked by a distinct lithologic change.

Throughout the area of occurrence in Montana (possibly exclusive of the southern and southeastern margins of distribution), the Devonian is conformably overlain by Mississippian strata of Kinderhook age. The precise Mississippian-Devonian contact is involved in a problem strikingly similar to that of the Chattanooga shale of the Mid-Continent area, and is discussed at length in this paper.

LITHOLOGY

The lithology of the Devonian of Montana may be most clearly and conveniently treated in terms of areas or provinces. Therefore, in the following discussion, the rocks encountered in (1) the Three Forks area in southern Montana, (2) the central Montana area, and (3) the northwestern Montana area, are discussed separately.

THREE FORKS AREA

The Three Forks area includes that part of Montana south of the Big Belt, Little Belt, and Big Snowy mountains. In this region occurs the well exposed section north of the Gallatin River at Logan, described and illustrated by Peale (1893, pp. 25-32), and from which he named the Jefferson and Three Forks formations. The Three Forks area thus includes what should be considered the type section for the Devonian of Montana.

Basal Devonian unit.—In the Three Forks area, the basal Devonian rocks are predominantly red shales, mudstones, and argillaceous dolomites, termed "Basal Devonian unit" on *United States Geological Survey Preliminary Chart 25* of Sloss and Laird. As previously stated, these beds are in apparent transition with underlying Cambrian strata and were formerly grouped with them in the Dry Creek shale. Further detailed mapping involving this part of the section is needed to

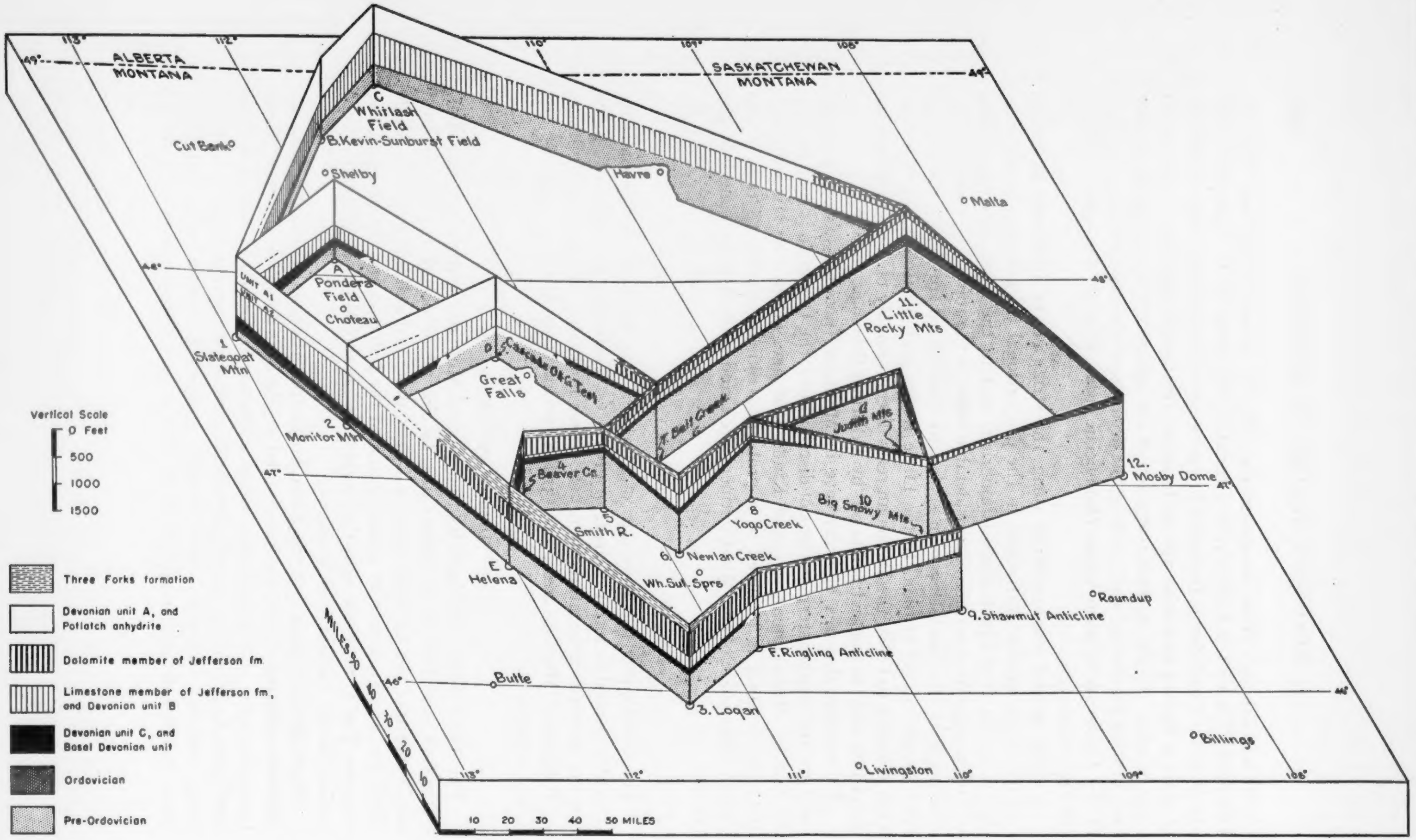

FIG. 2.—Isometric diagram showing relationships of Devonian strata in central and northwestern Montana. Reprinted from *U. S. Geol. Survey Prelim. Chart 25*, Oil and Gas Investig. Ser. (1946).

determine whether or not the "basal Devonian unit" should be established as a cartographic unit.

For purposes of detailed stratigraphy, however, the glauconitic, micaceous, and sandy shales associated with flat-pebble conglomerates, bearing trilobite fragments and phosphatic brachiopods, are here assigned to the Cambrian Dry Creek shale. The non-micaceous and less fissile shales and mudstones interbedded with rocks of Devonian type are placed in the Devonian; in the Logan section this "basal Devonian unit" is 24 feet in thickness. In most of the sections measured, this division does not permit the splitting of the strata sharply into definitely Cambrian rocks below and definitely Devonian rocks above, for 10 feet or more of strata bearing characteristics of both ages are present at most places. These intermediate rocks are termed "beds of undetermined age." Possibly more detailed examination will show them to be the result of reworking of Cambrian rocks by an advancing Devonian sea.

Pre-Upper Devonian topographic relief controlled the relative thicknesses of the basal Devonian unit and Dry Creek shale present at any one locality, and these relative thicknesses differ markedly in short distances. On Dry Creek, 10 miles northeast of the Logan section, for instance, a section measured by Peale (1893, pp. 24–25), exhibits more than 100 feet of flat-pebble limestone conglomerates interbedded with glauconitic shales beneath the basal Devonian unit, which is markedly thinner than at Logan. These strata, called "pebbly limestones" by Peale, are clearly Upper Cambrian in age and are lacking at the Logan section. Their absence must be ascribed to pre-Upper Devonian erosion.

The basal Devonian unit is in upward transitional contact with the limestone member of the Jefferson formation. The contact is marked by a change from red and yellow to gray and brown, and from predominantly argillaceous to predominantly carbonate rocks.

Limestone member of Jefferson formation.—The limestone member of the Jefferson formation is characterized by dark chocolate-brown, dense, massive limestones, in most places slightly dolomitic. Dark brown to black saccharoidal dolomites are common. The dolomites are interbedded with the limestones and are particularly conspicuous at the base of the member. Stromatoporoids are the most frequently observed fossils, but tetracorals and brachiopods have been found by careful search in several localities. The thickness of the limestone member in the Logan section is 240 feet.

The member is in transitional contact with the overlying dolomite member of the Jefferson. The contact is marked by a change from dense texture and predominant limestone composition to saccharoidal texture and dolomite composition.

Dolomite member of Jefferson formation.—The dolomite member of the Jefferson formation is characterized by massive, dark brown to black, saccharoidal dolomites, which form prominent ridges and cliffs. Where exposures are adequate, the upper 100 feet of the member exhibits red dolomitic shales interbedded with

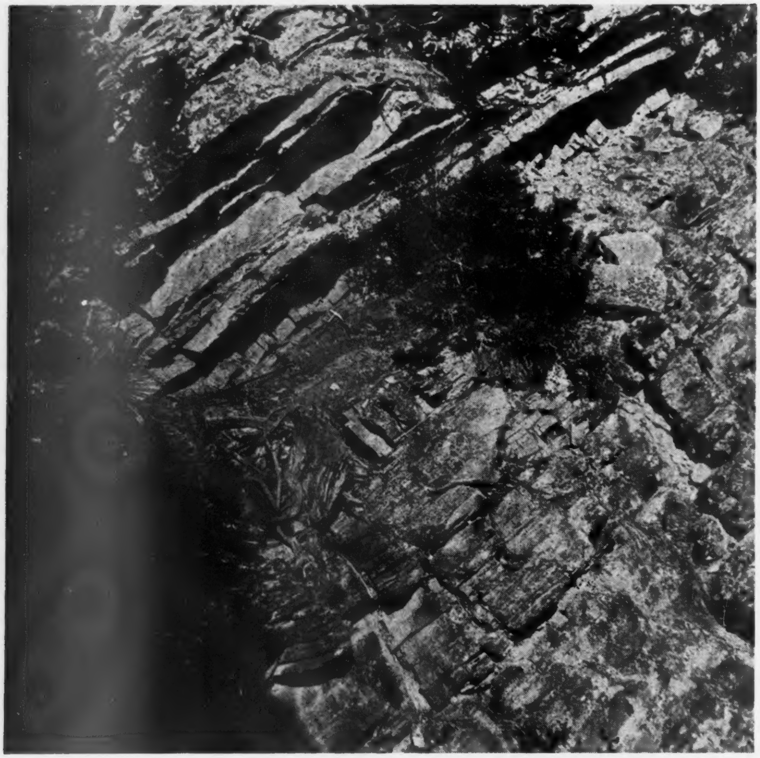

FIG. 3.—Devonian-Mississippian contact at Logan, Montana. Base of 2½ feet of black shale below pick near center of photograph is considered base of Mississippian. Above black shale are Mississippian limestones; below are slabby and sandy limestones of Sappington sandstone member of Three Forks formation.

coarse irregular breccias of the type resulting from the solution of evaporites. Commonly, in the Three Forks area, the breccia zone and the overlying non-resistant shale of the Three Forks formation are imperfectly exposed or entirely covered. In the interests of simpler areal mapping, it would be more logical perhaps to revise Peale's classification and assign the breccias and associated shales to the Three Forks formation; but where the breccias are well exposed, as in the type section, their genetic and lithologic relationships with the main body of dolomite below are clear. The thickness of the dolomite member in the Logan section is 475 feet.

The Jefferson formation is conformably overlain, with a fairly clear-cut contact in good exposures, by the shales of the Three Forks formation.

Three Forks formation.—The Three Forks formation is composed of dark brown dolomitic shale and shaly dolomite at the base, green plastic (probably in part bentonitic) shale interbedded with fossiliferous black limestone in the middle, and yellow-weathering sandy limestone and calcareous sandstone at the top. The sandy zone at the top was named the Sappington sandstone by Berry (1943, pp. 14–16) and assigned to the Mississippian because of a distinctive fauna characterized by *Syringothyris*. However, it can be demonstrated that the normal shale facies of the Three Forks, bearing the typical *Cyrtospirifer* fauna, is interbedded with the sandy facies bearing *Syringothyris*, and that the sandy facies grades laterally into typical shale of the Three Forks formation. The writers consider the "Sappington sandstone" to be a local member of the Three Forks formation. In the Logan section the Three Forks formation is 150 feet thick.

The Three Forks is conformably overlain by interbedded thin, black, crinoidal limestones and calcareous shales of the Lodgepole limestone of the Mississippian Madison group. Rarely, where exposures are perfect, 2–3 feet of fissile black shale mark the contact.

Devonian Section at Logan, Montana
Sec. 24, T. 2 N., R. 2 E., Gallatin County, Montana

	Feet
MISSISSIPPIAN	
Madison group	
Lodgepole limestone	
Dense to sparsely crinoid-fragmental limestone, interbedded with calcareous shale	?
Black fissile shale	2½
DEVONIAN	
Three Forks formation	
Massive, orange-weathering, yellowish gray to orange silty limestone at base, grading to fine calcareous sandstone at top	23
Cover	17
Yellow-weathering, sandy and silty limestone	9
Cover	11
Medium to dark brown fossiliferous limestone with *Cyrtospirifer*	6
Cover	4
Gray-green fissile shale, some plastic and bentonitic	2
Cover	8
Gray-green shale	15
Cover	1
Gray-green shale	15
Cover	6
Dark gray-green argillaceous dolomite in beds up to 1 foot, interbedded with gray-green dolomitic shale	5
Gray-green to dark gray argillaceous saccharoidal dolomite with light brown mottling, minor dark brown dense limestone at top	11
Orange to yellow argillaceous and silty dolomite with minute red specks	3
Cover	5
Total thickness Three Forks formation	150
Jefferson formation	
Dolomite member	
Massive, light to medium gray-brown limestone and dolomitic limestone, small brown chert nodules	10
Dense to finely saccharoidal brecciated dolomite and dolomite breccia with angular blocks up to 2 feet in diameter and including red and green shale fragments near base	55
Cover	25
Finely brecciated red shale, with green mottling	5

	Feet
Thin-bedded red argillaceous dolomite and dolomitic shale	15
Yellow-brown argillaceous saccharoidal dolomite with orange streaks and specks, and chert fragments	5
Light tan to dark brown saccharoidal limestone and dolomite, partial cover	40
Medium to dark brown saccharoidal dolomite. Some evidence of brecciation. Minor amounts light pinkish brown dense dolomite with secondary calcite and silica, partial cover	85
Medium to dark brown, fine to coarsely saccharoidal dolomite with minor amounts of light tan saccharoidal limestone, partial cover	50
Medium to dark brown, fine to coarsely saccharoidal dolomite, partial cover	92
Dark gray, massive, saccharoidal dolomite	15
Cover	10
Dark brown, massive, porous, saccharoidal dolomite. Round, dark chert nodules in lower 10 feet	63
Light gray-buff, finely saccharoidal dolomitic limestone	5
Total thickness dolomite member	475
Limestone member	
Dark gray brown dense limestone with light brown saccharoidal mottles. Numerous stromatoporoids, *Cladopora, et cetera*	15
Thin-bedded brown-gray saccharoidal dolomitic limestone	5
Massive, dark brown, dense limestone, minor amounts light yellow-brown limestone	46
Yellow-brown to dark brown dense limestone with saccharoidal spots and mottles. One foot of yellow saccharoidal limestone at base	9
Dense limestone as above; abundant stromatoporoids at top	20
Light to medium brown, dense to saccharoidal limestone	10
Brown saccharoidal dolomitic limestone and calcareous dolomite, interbedded with light gray and tan crystalline limestone	30
Dark brown coarsely saccharoidal limestone, thin-bedded	10
Dark brown dense to saccharoidal limestone	8
Brecciated brown saccharoidal limestone, considerable amount white secondary calcite	12
Light brown saccharoidal dolomitic limestone and medium brown saccharoidal dolomite	10
Dark brown dense limestone with nodules of dark brown chert	6
Thin-bedded, tan, dense limestone	5
Brown saccharoidal limestone and dolomite	10
Massive brown saccharoidal limestone	15
Evaporite-solution breccia, angular fragments up to 8 inches in diameter, of buff to brown, dense to saccharoidal limestone	10
Chocolate brown dense limestone, minor light brown saccharoidal limestone. Thin-bedded in lower 5 feet massive at top	15
Light brown saccharoidal and argillaceous limestone interbedded with minor amount dense chocolate limestone	5
Total thickness limestone member	240
Total thickness Jefferson formation	715
Basal Devonian unit	
Light buff and tan saccharoidal argillaceous limestone. Few silty streaks with fine quartz grains. Trace of glauconite at base. Minor evaporite-solution breccia near middle. A few vugs filled with solid hydrocarbon	17
Buff and red dolomitic siltstone	3
Buff silty dolomite with yellow and orange laminae	4
Total thickness basal Devonian unit	24
Total thickness Devonian strata	889
Beds of undetermined age	
Red argillaceous and silty dolomite, laminated at top with light gray dolomite. Some red dolomitic siltstone and dove gray dense dolomite. Trace of glauconite	11
Red argillaceous dolomite and flesh pink dolomite with red flecks, laminated with light gray and yellow limy siltstone	10
Red argillaceous dolomite with light gray, pink and orange laminae. A little red, finely micaceous shale	9
Gray, dense to sparsely crystalline dolomite and dark red, silty and sandy limestone	4
Massive, pale yellow silty and glauconitic limestone with rounded and spherical quartz grains. Pink mottling near top	12
Light gray dense to finely saccharoidal calcareous dolomite, glauconitic	5
Total thickness, beds of undetermined age	51

CAMBRIAN	Feet
Dry Creek shale	
Pebbly dolomitic siltstone and silty dolomite, glauconitic and with red mottles and red shale flecks	10
Gray, micaceous quartzitic siltstone and red micaceous shale with phosphatic brachiopods	2
Cover	8
Gray-green micaceous silty shale	6
Thin-bedded gray-green dolomite with partings of green micaceous shale	5
Green fissile shale, micaceous and worm-tracked; few thin beds of gray and tan pebbly dolomite	14
Total thickness Dry Creek shale	45
Pilgrim limestone	
Mottled and pebbly, light gray to dark brown, dense to oölitic limestone	?

CENTRAL MONTANA

The central Montana area of Devonian exposures includes the Big and Little Belt mountains, Big Snowy Mountains, Judith Mountains, and Little Rocky Mountains. Further information is supplied by a few wells that were drilled into or through the Devonian.

The Devonian of central Montana reflects the influence of a temporary positive axis at the approximate position of the present axis of the Little Belt-Big Snowy-Porcupine trend. Stratigraphic sections measured at various positions with reference to this Devonian positive axis of central Montana exhibit wide variations in the thickness and in the number of the members represented.

Basal Devonian unit.—The basal Devonian unit may be recognized at all exposures in central Montana excepting in the Big Snowy Mountains which are near the southeastern margin of Devonian distribution. The unit exhibits the same lithologic character and local variations in thickness as in the Three Forks area. It is in conformable and transitional contact with the overlying limestone member of the Jefferson formation, where that member is present, or with the dolomite member where the limestone member is absent. This relationship makes it apparent that the deposition of the basal unit transgressed time boundaries and occurred at the beginning of Devonian deposition—early in the lower parts of the basin, later on the higher areas of the Devonian positive axis of central Montana.

Throughout most of its area of distribution in central Montana, the basal unit rests with apparent conformity on upper Cambrian strata. The contact between the beds of the two different ages presents the same problems as those encountered in the Three Forks area. In the Little Rocky Mountains—the northeast corner of the central Montana area—the Devonian overlies Upper Ordovician. Here the basal unit is 50 feet thick and consists of reddish and greenish shaly dolomite, resting with sharp contact on Ordovician dolomite assigned to the Big Horn dolomite.

In his work on the Little Belt Mountains, Weed (1900, p. 286, Pl. XI), described thin-bedded limestones interbedded with gray or greenish shale and grading into "rather pure thick-bedded limestones." To these beds he gave the name Yogo limetone, and assigned them to the Cambrian. It is evident that

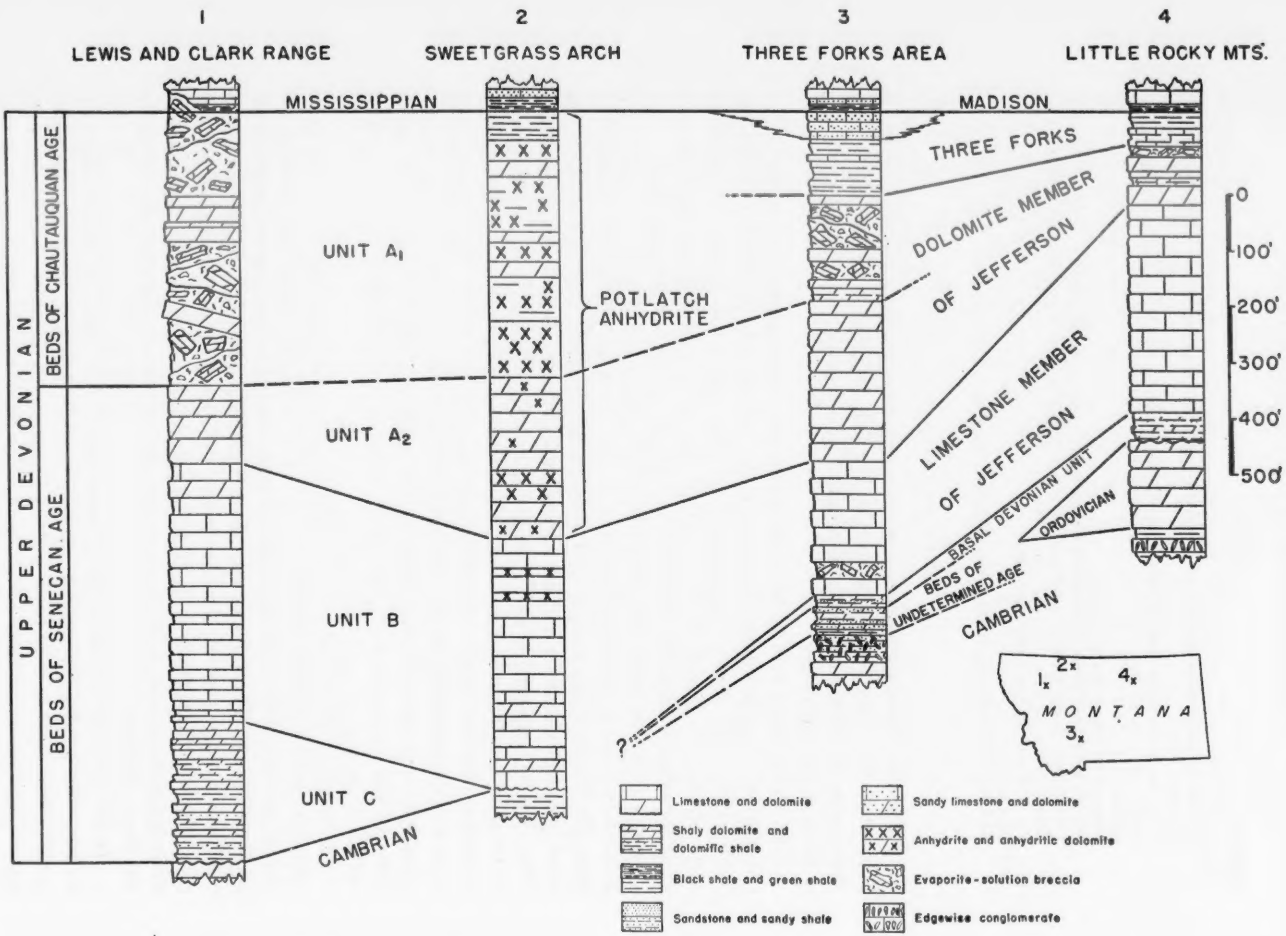

FIG. 4.—Generalized stratigraphic columns illustrating Devonian correlations in central and northwestern Montana.

Weed considered the Yogo limestone equivalent to Peale's "pebbly limestones" of the Three Forks area.[4] It now seems clear that Weed's Yogo limestone is equivalent to the basal Devonian unit of this paper, plus a variable part of the base of the limestone member of the Jefferson formation. If the basal Devonian unit is proved to be a cartographic unit, Yogo, suitably revised, would have priority as a formational name.

The following section in the Little Belt Mountains, on Yogo Creek at the mouth of Bear Gulch, is fairly typical for the area.

YOGO CREEK SECTION
Sec. 1, T. 13 N., R. 10 E., Judith Basin County

	Feet
DEVONIAN	
Jefferson formation	
Dolomite member	
Dark brown to black, massive saccharoidal dolomite	?
Limestone member	
Dark brown to black, dense to finely saccharoidal dolomitic limestone, with a few thin beds of highly organic black shaly limestone bearing *Lingula* and shark teeth. Eight feet of yellowish brown slightly argillaceous dolomitic limestone at base	35
Basal Devonian unit	
Yellow-brown and dark gray-brown dolomitic shale interbedded with shaly, fine to medium saccharoidal dolomite	10
Light olive yellow highly argillaceous thin-bedded dolomite with calcite-lined vugs, one inch in diameter	10
Gray-brown highly argillaceous dolomite with mottling of yellow saccharoidal dolomite and scattered round sand grains. One foot of yellow dolomitic shale at base	10
Mudstone, salmon-colored with yellow-green spots, interbedded with brick-red. Scattered round sand grains and trace of glauconite	7
Mudstone, brick-red and chunky, slightly dolomitic; some silt grains and poorly sorted, angular sand grains	3
Total thickness, basal Devonian unit	40
Beds of undetermined age	
Shale, maroon, fissile, slightly dolomitic	8
CAMBRIAN	
Dry Creek shale	
Dolomite, light yellow, red-stained, cavernous and saccharoidal with 1 foot of red fissile shale in middle. Abundant silt and glauconite; trilobites and phosphatic brachiopods	2
Shale, red and green micaceous, fissile; with 2-inch beds of dense to finely crystalline limestone bearing trilobite fragments	1
Shale, very finely micaceous and silty, green at base, grading to red at top	6
Limestone conglomerate, flat pebbles of dense gray limestone with few of red argillaceous limestone. Abundant glauconite	2
Shale, green with minor pink and yellow. One foot of edgewise conglomerate in middle. Abundant glauconite	3
Limestone, light gray, dense, with edgewise conglomerate of same lithologic character. Abundant glauconite	16
Shale, altered to argillite by andesite sill; phosphatic brachiopods	4
Total Cambrian exposed	34

[4] Deiss (1936, p. 1272) found no Cambrian fossils above the Dry Creek shale, and states that, "Consequently, there are no beds which can possibly be called Cambrian, and therefore Yogo, in the Belt Creek section." Deiss further states (1936, p. 1337), "The name *Yogo* has no basis in observable fact and must be discarded." The writers agree that there may be no Cambrian above the Dry Creek shale in central Montana, but it is not apparent why this fact in itself should invalidate the term *Yogo*. If the formation is a lithologic unit, its identity is not destroyed because it was first assigned to the wrong geologic age.

FIG. 4.—Generalized stratigraphic columns illustrating Devonian correlations in central and northwestern Montana.

Limestone member of Jefferson formation.—The limestone member of the Jefferson formation displays, in varying thickness and lithologic character, the greatest influence of the Devonian positive element of central Montana. Along the axis of the element the member is reduced to a barely recognizable thin calcareous transition zone a few tens of feet thick between the basal Devonian

FIG. 5.—Jefferson formation on Belt Creek, Little Belt Mountains. In this area dark dolomite member rests with sharp contact on lighter-colored limestone member.

unit and the dolomite member of the Jefferson. Here it is characteristically composed of light gray or light yellow-brown silty limestones with a few interbedded dark brown dense limestone strata bearing stromatoporoids. North and south of the positive axis, the member increases in thickness to 200 or 300 feet of dense dark brown fossiliferous limestone indistinguishabe from the equivalent part of the section in the Three Forks area.

Where present, the limestone member of the Jefferson is in transitional contact with the underlying basal Devonian unit. North and south of the positive axis, the member is also transitional with the overlying dolomite member. Here and there along the axis of the positive element, however, the latter contact is marked by an abrupt change from limestone to dolomite, by differences in color and size of grains, and by a channeled surface which indicates a minor erosion interval or cessation of deposition between the two members. Such an abrupt change can be seen on the east side of Belt Creek about 3 miles above Monarch in the Little Belt Mountains.

Dolomite member of Jefferson formation.—Throughout the central Montana area the dolomite member of the Jefferson formation characteristically consists of massive saccharoidal dolomite varying in color from light tan and buff to, more commonly, dark brown or black. Outcrops of the upper part of the member display evaporite-solution breccias, while the few wells drilled into the Devonian in central Montana encountered anhydrite or anhydritic dolomite at the same stratigraphic position. Exceptions to the rule are found in the Little Rocky and Big Snowy mountains In the Little Rockies, red, yellow, and green argillaceous dolomite forms a prominent break near the middle of the member. In the Big Snowies the top of the member is marked by an irregular reef-like accumulation of coralline débris. The thickness of the dolomite member varies widely from 90 to 470 feet. In general, however, it thins from west to east.

The following section in the Big Snowy Mountains illustrates the character of the dolomite member at its most southeasterly exposure.

Swimming Woman Canyon Section
West Wall of Swimming Woman Canyon, Big Snowy Mountains
Sec. 5, T. 11 N., R. 19 E., Golden Valley County, Montana

	Feet
MISSISSIPPIAN	
Madison group	
Lodgepole limestone	
Basal 100 feet consists of highly argillaceous, black, dense limestones with a few crinoidal beds and one zone of dark brown to black saccharoidal dolomite	?
Black fissile shale bearing conodonts	5
DEVONIAN	
Three Forks formation	
Covered interval with float fragments of light orange, finely saccharoidal, argillaceous dolomite	15
Jefferson formation	
Dolomite member	
Breccia of buff, finely saccharoidal, argillaceous dolomite in matrix of tan dolomite	3
Dolomite, cream buff, medium to coarsely saccharoidal, with zones of strong intercrystalline and vuggy porosity and porous coralline zones	14
Cover	14
Dolomite, tan, medium to coarsely saccharoidal, leached and vuggy, with limonite stain and secondary quartz crystals	7
Dolomite, tan, coarsely saccharoidal. Trace of porosity	20
Dolomite, tan, coarsely saccharoidal, interbedded with medium brown, finely saccharoidal, dolomite	10
Dolomite, buff to light brown, finely to medium saccharoidal	15
Dolomite, medium brown, medium to coarsely saccharoidal, porous	30

	Feet
Dolomite, light buff to tan, finely saccharoidal, interbedded with dolomite, medium brown, coarsely saccharoidal	20
Dolomite, flseh pink, slightly argillaceous, finely saccharoidal, interbedded with yellow-brown and dark gray coarsely saccharoidal dolomite (rests with barely perceptible angularity on Cambrian)	5
Total thickness Jefferson formation	138

CAMBRIAN

Interbedded, light gray, dense limestone, edgewise flat-pebble conglomerate and silty, micaceous, glauconitic shale

Three Forks formation.—The Three Forks formation is rarely well exposed in central Montana. Averaging about 100 feet in thickness, the formation commonly forms a débris-covered bench overlying the resistant Jefferson formation. Gray-green dolomitic shale and shaly dolomite, with minor beds of bentonitic green shale, comprise most of the formation; but the most conspicuous types of rock in partly covered sections are orange, yellow, and maroon argillaceous limestone and dolomite. Evaporite-solution breccias are present at most localities.

The contact with the underlying Jefferson formation is conformable and transitional. The upper contact of the Three Forks is placed at a black, fissile shale marking the base of the Mississippian.

NORTHWESTERN MONTANA

The northwestern Montana province includes areas of Devonian exposures in the Swan, Flathead, Lewis and Clark, and Sawtooth ranges, and the plains area east of the mountain front, including the Sweetgrass arch, where scattered subsurface data are available. This is a small part of a larger province which includes much of central and southern Alberta.

Stratigraphic terminology used in the central part of the state is not readily applicable in the northwestern part. Preliminary work by Deiss (1933) in the outcrop areas resulted in the naming of several members assigned to the Jefferson formation. In a later paper, Deiss (1943, pp. 228–31) recognized that the term Jefferson was misapplied and assigned the named members to an "unnamed formation." The several members proposed by Deiss have not been readily applicable and are not used in this report. For the present, and until adequate stratigraphic terms, based on additional stratigraphic and areal work, are proposed, the subdivisions of the Devonian are assigned, as in the *United States Geologic Survey Preliminary Charts 15 and 25* (Sloss and Laird, 1945, 1946), to units that are designated by letter and number in order of penetration by drilling.

Devonian Unit C.—In the mountain areas of northwestern Montana, unit C, the basal unit of the Devonian, disconformably overlies a channeled surface of some relief (20–30 feet) on the Upper Cambrian Devils Glen dolomite. East of the mountain front, it rests on Cambrian shales. The easily recognizable disconformity makes possible a clear definition of the unit, which is in contrast to the indefinable lower boundary of the equivalent basal Devonian unit in central Montana and the Three Forks area. The upper contact is marked by a fairly abrupt transition from shale and shaly dolomite to the limestones of Devonian

unit B. The unit thins markedly from west to east, being 400 feet thick on the east flank of the Swan Range, 100 feet thick at the Pondera field, and absent on the higher parts of the Sweetgrass arch.

Unit C consists of red and green dolomitic shales and mudstones interbedded with brown and reddish brown argillaceous and sandy dolomites, the latter in many places highly lenticular. The unit forms a conspicuous, brightly colored bench between the resistant white Devils Glen dolomite below and the cliff-forming limestones of Devonian unit B above, and should be an easily mapped unit west of the Sawtooth Range. At the western margin of exposure, on the east flank of the Swan Range, the unit is exposed over large areas in localities of low

FIG. 6.—Part of Devonian section on southwest flank of Slategoat Mountain, Lewis and Clark Range, showing basal beds of Devonian unit A_2, units B and C, and Cambrian Devils Glen dolomite (Ꞓdg).

dip and simple structure. The unit includes the Glenn Creek and White Ridge members of Deiss, but the division into two members is not apparent, except locally.

Devonian Unit B.—Devonian unit B, the equivalent of the limestone member of the Jefferson formation, rests conformably on unit C, excepting on the higher parts of the Sweetgrass arch, where unit B disconformably overlies Cambrian shales. The upper contact is marked by the base of the saccharoidal dolomites of unit A and the top of the dense limestone of unit B.

Devonian unit B thins from about 650 feet at Spotted Bear Mountain on the western margin of outcrop to about 260 feet in the Cobb Hirshberg well in Sec. 23, T. 27 N., R. 4 W., in the Pondera field. From there in a northerly and northeasterly direction it thickens again to 600 feet in the Whitlash field.

Unit B is dominantly brown to brownish gray dense limestone, slightly argillaceous near the base. A few thin zones of saccharoidal dolomite are present, and some of the limestones bear globular segregations of olive brown saccharoidal limestone or dolomite. Many beds are marked by anastomosing worm burrows or solution channels filled with yellowish argillaceous limestone. The unit is well bedded and tends to form steep cliffs. In the subsurface the limestones contain a few thin anhydrite beds, and a few thin evaporite-solution breccia zones appear in outcrops. The units appears to be equivalent to the Cooper's Lake member of Deiss.

Devonian Unit A.—The contact between unit A and the overlying Mississippian strata is a subject of considerable dispute among geologists of Montana and Alberta. In the outcrop areas of northwestern Montana, the contact is obscured in most places by slumping and brecciation accompanying the removal of anhydrite. In the subsurface of the Sweetgrass arch and southern Alberta and, as exposed along the mountain front in Alberta, sufficient information can be gained to clarify the problem.

In the mountain-front exposures in Alberta, the equivalent of Devonian unit A, the upper (Palliser) member of the Minnewanka formation, is conformably overlain by the black, fissile Exshaw shale assigned to the Devonian by Warren (1937, pp. 454–57) because of its *Tornoceras* fauna. In the subsurface of the Sweetgrass arch in Montana and in southern Alberta, the black shale overlies green shales and anhydritic dolomites of unit A and bears a Mississippian conodont fauna. On these grounds, various authorities have placed the Devonian-Mississippian contact above or below the black shale. The present paper does not pretend to evaluate the paleontologic time boundary, which may well vary from place to place with respect to the black shale. In terms of lithogenetic boundaries and cartographic units, however, it is clear from the sharp lower contact of the black shale and its upward transition into the Banff formation or the Madison limestone, that the lithogenetic and cartographic top of Devonian units is the base of the black shale.

In the mountains of northwestern Montana, the Devonian-Mississippian contact was misinterpreted by Deiss (1933, pp. 44–45; 1943, p. 243) as a disconformity involving erosion or non-deposition of approximately 425 feet of Devonian prior to Mississippian deposition. This misconception arose from interpreting the evaporite-solution breccias of Devonian unit A as the basal conglomerate of the Mississippian. The base of the breccia zone is irregular and, if interpreted as a Mississippian depositional feature, the breccias would appear as evidence of pre-Mississippian disconformity. It is the writers' opinion that, in the northern Rocky Mountain province as a whole, there was only slight and local pre-Mississippian emergence, with almost uninterrupted deposition in most areas. Such local areas as may have been emergent suffered only slight reworking of Devonian sediments before Mississippian sedimentation began.

In the subsurface, unit A is characterized by massive anhydrite interbedded with brown, dense to saccharoidal dolomites, the dolomite increasing and the

anhydrite decreasing toward the base. At the top is 20–60 feet of green and gray-green non-calcareous shale; similar shale appears in minor amounts interbedded with anhydrite and dolomite throughout much of the unit. Unit A is equivalent to the Three Forks formation and the dolomite member of the Jefferson, and some subsurface stratigraphers have attempted to apply these terms to the Sweetgrass arch, assigning the green shales to the Three Forks and the anhydrite and dolomite to the Jefferson. Such usage has resulted in confusion and lack of conformity among workers.

The base of the green shale is not definable, for the shale is interbedded and transitional with anhydrite and dolomite through 100 feet or more of section; therefore, the limits of the "Three Forks formation" on the Sweetgrass arch can not be established, and the "formation" is not a lithologic entity. If the base of the Three Forks is indefinable, it follows that the Jefferson can not be applied as a formational name; hence, it is preferable to abandon both terms for the area.

The most easily established horizon in the Devonian of the Sweetgrass arch is between the anhydrite and dolomite of unit A and the dense limestone of unit B. This break was recognized by Perry (1929, p. 5), who proposed the term "Potlatch anhydrite" in the Kevin-Sunburst field for what the writers have named unit A. The term "Potlatch" is applicable throughout the Sweetgrass arch subsurface and has been adopted by Alberta geologists. Its continued use is strongly recommended over "Three Forks" and "Jefferson" for the subsurface of the area in question. The thickness of the Potlatch anhydrite in the Sweetgrass arch area in the wells studied ranges from 530 to 830 feet.

In outcrop areas, the anhydrite of unit A has been removed by solution, causing slumping and brecciation of much of the upper three-fourths of the unit and making possible a division into two subunits: A_1, the breccia zone at the top, and A_2, relatively non-brecciated dolomite below. The breccia zone occupies the same stratigraphic position as the major anhydrite zones of the subsurface Potlatch and, in spite of its genesis, is remarkably persistent. The breccia is composed of angular blocks ranging from a fraction of an inch to several tens of feet across, firmly cemented by dense to saccharoidal brown limestone or dolomite. The blocks are composed chiefly of dense to saccharoidal dolomites of the type found interbedded with anhydrite on the Sweetgrass arch. Many of the dolomite blocks appear to have been derived from massive brown and gray beds, but light tan and buff blocks which weather into thin plates and laminae are common. Here and there are blocks of black shaly limestone and crinoid-fragmental limestone, slumped into the brecciated zone from the base of the overlying Mississippian. The breccia contains relatively undisturbed sequences of strata which represent dolomite beds of sufficient thickness to be unaffected by solution of anhydrites.

The total thickness of the exposed beds of unit A ranges from 440 to 695 feet. This unit thickens toward the east as the Potlatch anhydrite of the subsurface and in the Pondera field is 820 feet thick. From the Pondera field north and east across the Sweetgrass arch the Potlatch thins.

In the areas visited by the writers, the breccia was found to be best developed

in the Flathead and Lewis and Clark ranges, the western part of the outcrop belt, where the breccia forms impressive outcrops. In the Sawtooth Range, area of the most easterly outcrops, north of Sun River, unit A_1 is dominated by dark brown to black dense to saccharoidal limestones, many of which are brecciated but re-cemented in place. True breccia zones are common but not conspicuous, and the lithologic character is not dissimilar to that of the uppermost part of the Minnewanka formation of the Alberta mountain front. Actual transition of the A_1

FIG. 7.—Evaporite-solution breccia in unit A_1 on Pentagon Mountain, Lewis and Clark Range. Note erratically disposed blocks firmly cemented in matrix. Rod is 5 feet long.

breccias into the non-brecciated upper Minnewanka can not be traced, because the Lewis overthrust obliterates all Paleozoic outcrops in the Glacier Park area north of the Marias River.

South of the Sun River in the Sawtooth Range, the lower breccias are well developed, but the upper part of A_1 contains abundant greenish brown dolomitic shales and shaly dolomites, which, although perhaps subject to the same elimination of interbedded anhydrite, do not display prominent brecciation unless examined under the microscope. The argillaceous composition of part of the unit in the southern Sawtooth Range approaches in facies the Three Forks formation in the areas at the south, but recognition of the Three Forks as a mappable unit is not possible.

For want of a shorter or more euphonious name, the writers have used the term "evaporite-solution breccias" for breccias which can be demonstrated to

have resulted from the removal of evaporites. It seems probable that such breccias are to be found in most areas where evaporite-bearing strata crop out, such as anhydrite-bearing Mississippian and Pennsylvanian strata exposed in Montana, Wyoming, and the Black Hills, but published reports contain few references that can be so interpreted. The Devonian evaporite-solution breccias of northwestern Montana must have been formed after early Mississippian time, since they contain slumped fragments of Mississippian rocks which were thoroughly indurated before becoming involved in the brecciation. The breccias are cut by middle (?) or late (?) Tertiary block faults, and were sufficiently indurated by Pleistocene time to stand as cirque walls and thin, knife-like aretes.

If it be assumed that ground-water circulation was necessary for solution of the anhydrite, then the elevation requisite to that movement must have occurred between early Mississippian and middle (?) Tertiary. During this interval, the region was subject to two periods of widespread uplift, (1) late Paleozoic to early Mesozoic movements of the Sweetgrass arch, and (2) late Cretaceous to early Tertiary Laramide movements. Uplift of the Sweetgrass arch must be ruled out, for the evaporitesare preserved on the higher parts of that element. The Laramide thrusts of northwestern Montana show no preferential orientation with respect to the breccia, and there are no décollements or other effects that might be expected if the evaporites were involved in the thrusting. Therefore, it is the writers' opinion that solution of the evaporites and consolidation of the breccia took place during a time of broad anticlinal uplifts closely following the initiation of Laramide movements and prior to thrusting.

Unit A_2 is almost without breccia and consists of massive, brown, coarsely saccharoidal dolomite. Individual beds are markedly cross-laminated and, with their granular texture, closely resemble sandstones on casual inspection. However, insoluble residues contain no sand grains, and microscopic examination in thin section reveals an aggregate of euhedral dolomite rhombs. It is suggested that the minute crystals were precipitated from solution and laminated by currents before lithification. In lithologic character and stratigraphic position, A_2 is equivalent to the lower part of the dolomite member of the Jefferson formation, but the central Montana terms are not applicable in the outcrop areas of northwestern Montana because the upper part of the dolomite member of the Jefferson is equivalent to the lower part of the evaporite-solution breccia zone, which extends upward to include equivalents of the Three Forks.

The following section from the Lewis and Clark Range is typical for the area.

SECTION ON SOUTH FLANK OF SLATEGOAT MOUNTAIN AT HEAD OF GLENN CREEK
Sec. 10, T. 22 N., R. 11 W., Lewis and Clark County, Montana

MISSISSIPPIAN

Basal beds of Mississippian, composed of black dense limestone and black calcareous shale interbedded with gray to brown, crinoid-fragmental, limestone and gray and brown chert. Irregular breccia zones extend up from Devonian, cutting across Mississippian bedding to 25 feet above base. Mississippian-Devonian contact obscured by 8-foot covered interval

	Feet
DEVONIAN	
Unit A_1	
Dolomite, light brown, saccharoidal	2
Cover	10
Breccias, pebbles of thin-bedded gray dolomite and brown dolomite in gray dolomite matrix. Abundant stromatoporoid fragments	105
Dolomite, brownish yellow, thin-bedded, brecciated	3
Dolomite, light gray to yellow-brown, thin bedded, argillaceous	12
Breccia, massive, ledge-forming, with angular boulders of gray and brown saccharoidal dolomite, some thin-bedded, up to 3 feet in diameter	30
Dolomite, very thin-bedded, argillaceous, buff	5
Dolomite, gray-brown, dense	6
Dolomite, brown, saccharoidal, thin-bedded	2
Breccia, pebbles up to 8 inches diameter of light gray thin-bedded and brown saccharoidal dolomite in matrix of gray, dense to finely saccharoidal dolomite	8
Dolomite, brown, thin-bedded, coarsely saccharoidal	4
Dolomite, brown, saccharoidal, with small gray chert nodules	5
Dolomite, brecciated, brown, saccharoidal	18
Breccia, pebbles of brown saccharoidal dolomite with a few of white saccharoidal dolomite in light brown dolomite matrix. Poorly preserved compound corals near base	57
Breccia, pebbles and boulders of white, dense to finely saccharoidal, thin-bedded dolomite in matrix of brown, dense to finely saccharoidal dolomite and dolomitic limestone. Few fragments of black Mississippian chert and crinoid-fragmental limestone	210
Total thickness Devonian unit A_1	477
Unit A_2	
Dolomite, brown, massive, coarsely saccharoidal, porous	60
Dolomite, light gray, dense	2
Dolomite, brown, massive, saccharoidal, porous. One foot of light brown, light gray-weathering dolomite near base	33
Limestone, dolomitic, light gray, white-weathering, dense, with breccia of brown saccharoidal dolomite pebbles at top. Bed forms a prominent marker on cliffs	2
Dolomite, brown, coarsely saccharoidal, cross-laminated	11
Dolomite, light brown, saccharoidal	2
Dolomite, dark brown, saccharoidal	2
Dolomite, light brown, light-weathering, saccharoidal; prominent marker on cliffs	1
Dolomite, brown, coarsely saccharoidal, porous, cross-laminated at base	22
Total thickness Devonian unit A_2	135
Unit B	
Limestone, dolomitic, dark brown, dense. Compound corals	5
Dolomite, brown, finely saccharoidal, interbedded with dolomite, white, coarsely saccharoidal	5
Dolomite, olive brown, dense to finely saccharoidal	5
Limestone, brown, with fine laminae of light brown, finely saccharoidal dolomite	5
Covered	5
Dolomite, calcareous, olive drab, dense	10
Limestone, chocolate brown, massive, dense	65
Limestone, dark brown to black, dense, thin-bedded	70
Limestone, chocolate brown, dense	84
Dolomite, reddish brown, saccharoidal, thin-bedded, porous, argillaceous	1
Dolomite, calcareous, brown, finely saccharoidal, covered interval (5 feet) near middle	20
Limestone, dark chocolate brown, dense; some thin-bedded; most in beds up to 2½ feet thick; numerous branching solution channels filled with fine breccia, upper beds with numerous stromatoporoids and mottling of brown saccharoidal dolomite. Abundant brachiopods near base	60
Dolomite, light gray and tan, finely saccharoidal, interbedded with limestone, chocolate brown, dense, partly covered	19
Limestone, finely saccharoidal, thin-bedded	1
Limestone, chocolate brown, dense, with yellow mottling on bedding planes, thin-bedded near base, massive above; numerous brachiopods, stromatoporoids at top	82
Dolomite, argillaceous, light brown, weathering to prominent yellow zone, thin-bedded	7
Limestone, chocolate brown, cense, massive, vuggy porosity at top	6
Limestone, chocolate brown, dense, contains solution cavities filled with limestone pebbles in argillaceous matrix	1
Limestone, dolomitic, brown, saccharoidal, finely laminated	9
Total thickness Devonian unit B	460

	Feet
Unit C	
Dolomite, argillaceous, light tan to brown, saccharoidal, some beds with red mottling	11
Shale, green	7
Dolomite, argillaceous, greenish brown	2
Breccia, pebbles of brown saccharoidal dolomite in dense dolomite matrix	2
Dolomite, brown, saccharoidal, porous	3
Limestone, chocolate brown, dense, with fine light brown laminae	2
Dolomite, brown, argillaceous	2
Shale, green	1
Breccia, angular pebbles up to 2 inches diameter of brown dolomite and green shale in matrix of greenish brown argillaceous dolomite	10
Dolomite, brown, argillaceous, saccharoidal	9
Shale, green, and brown argillaceous dolomite	9
Dolomite, argillaceous, brown, saccharoidal, porous	5
Dolomite and dolomitic shale, brown, thin-bedded	10
Dolomite, brown, saccharoidal, porous	2
Shale, green, interbedded with argillaceous dolomite, greenish brown, thin-bedded	2
Dolomite, brown, saccharoidal, porous, massive	3
Dolomite, argillaceous, and dolomitic shale, brown and greensih brown, with green shale partings	15
Dolomite, brown, massive, saccharoidal, porous	15
Shale, green with few reddish beds, interbedded with greenish, saccharoidal, argillaceous dolomite	45
Shale and mudstone, green	20
Shale and mudstone, green and maroon, with lenses of argillaceous dolomite	9
Breccia, pebbles of argillaceous dolomite in green and red shale matrix	1
Shale and mudstone, green and maroon, with lenses of argillaceous dolomite	2
Dolomite, greenish gray, thin-bedded, with thin green shale partings	8
Shale, green, with lenses of greenish saccharoidal argillaceous dolomite	10
Dolomite, sandy and argillaceous, green	3
Dolomite, greenish brown, argillaceous, in beds up to 2 feet thick	12
Dolomite, argillaceous, finely saccharoidal, interbedded with dolomite, highly porous, coarsely saccharoidal	5
Dolomite and limestone, yellow, green, brown, and gray, with thin green shale partings	5
Limestone, light brown, translucent (gypsiferous ?)	1
Dolomite, greenish brown, saccharoidal, and shale, green	3
Dolomite, cream white, dense	1
Shale, dolomitic, light brown	1
Shale, green and brown, with lenses of cross-laminated, sandy, orange brown dolomite; small lentil of white oölitic limestone	12
Dolomite, orange brown, sandy	2
Shale, green and brown, with lenses of rubbly argillaceous brown dolomite and thin-bedded sandy dolomitic shale. Few plant (?) fragments	5
Total thickness Devonian unit C	255
Total thickness Devonian	1327
CAMBRIAN	
Devils Glen dolomite	
Dolomite, light gray to light brown, some pink stained, finely to coarsely saccharoidal some highly porous. Massive cliff-former with 5 to 10 feet of relief on pre-Devonian surface	

AGE AND CORRELATION

Figure 8 illustrates the writers' current concept of the intrastate correlation of the Devonian of Montana and correlations with the standard time scale and with Devonian formations of Alberta. This concept has been in a process of evolution for several years; publication of the correlation chart does not signify the attainment of the end of that evolutionary process. The following discussion summarizes the paleontologic evidence for establishing age and correlation of the various units.

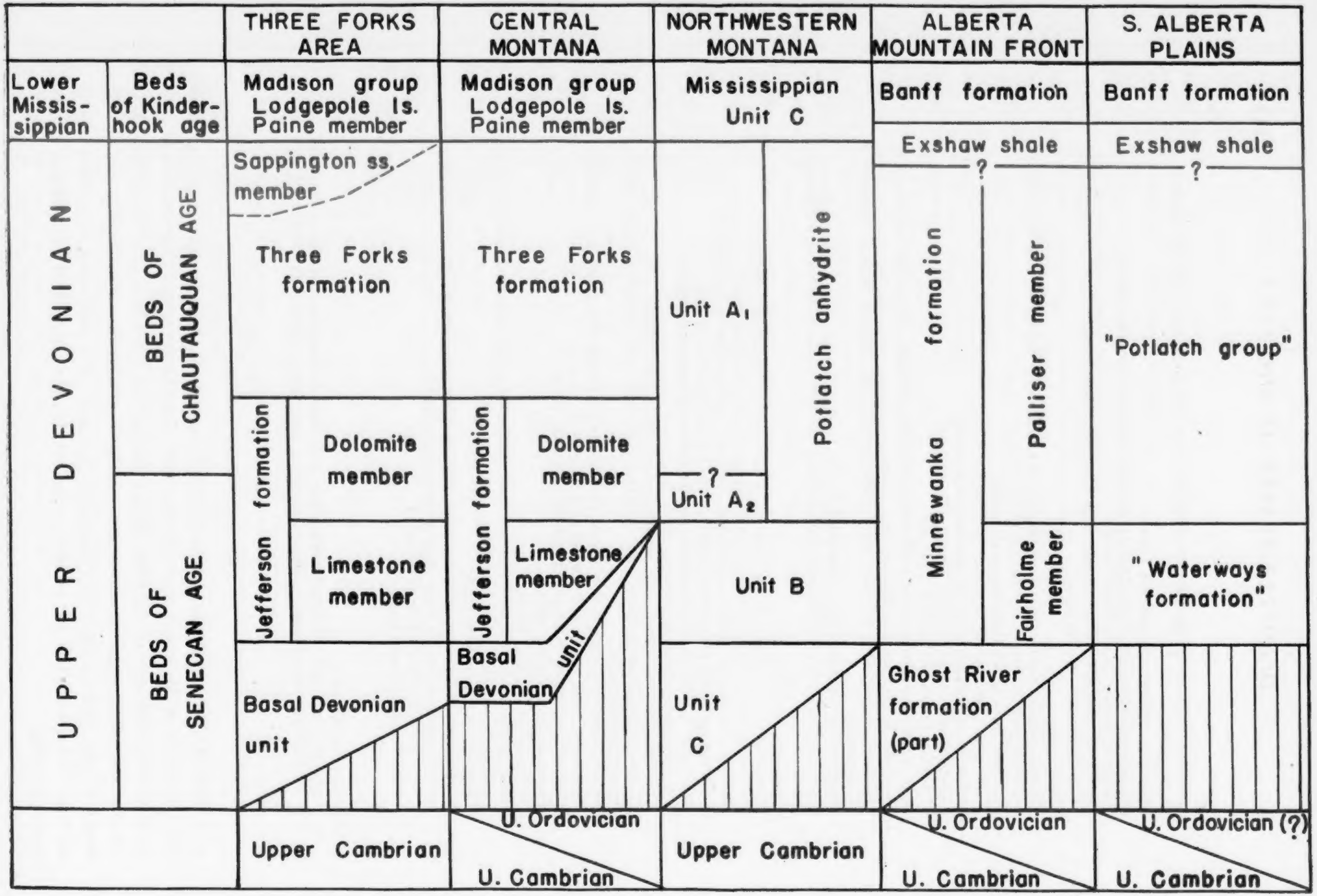

FIG. 8.—Correlation of Devonian strata of Montana and southern Alberta.

Conodonts from a black shale lens in unit C of the Flathead Range provide the stratigraphically lowest fauna known in the Devonian of Montana. No similar assemblage has been reported from the Cordilleran area, but, according to C. L. Cooper (1946, p. 612), the conodonts include "a preponderance of forms of Senecan age from the lower New Albany shale of Indiana and the Rhinestreet shale of New York," thus establishing the Upper Devonian age of the lowest strata. Because of lithologic character and similarity of stratigraphic position, the basal Devonian unit of central Montana and the Ghost River formation of Alberta are thought to be, in part, correlative of unit C.

The next oldest fauna is found in the lower three-fourths of both unit B and the limestone member of the Jefferson. It is abundant in certain localities in northwestern Montana, but is scarce enough to require close search in central Montana and the Three Forks area. The fauna includes the following.

Corals
- *Disphyllum colemanense* (Warren)
- *Disphyllum* sp.
- *Thamnophyllum* sp.

Brachiopods:[5]
- *Atrypa missouriensis* Miller
- *Atrypa* cf. *A. montanensis* Kindle
- *Atrypa spinosa* var. *montanensis* Kindle
- *Camarotoechia saxatilis* Hall
- *Cyrtospirifer whitneyi* (Hall) (?)
- *Leptostrophia* sp. cf. *L. camerata* Fenton and Fenton
- *Productella* sp. cf. *P. walcotti* Fenton and Fenton
- *Schizophoria iowaensis* Hall
- *Spirifer engelmanni* Meek
- *Spirifer jasperensis* Warren
- *Spirifer raymondi* Haynes
- *Strophonella* sp. cf. *S. reversa* Hall
- *Stropheodonta* sp.

The occurrence of the related group of spirifers, *S. jasperensis*—*S. engelmanni*, —*S. raymondi*, plus *Disphyllum colemanese*, makes apparent the correlation of this fauna with the "*Spirifer jasperensis* zone" of the Minnewanka of Alberta (Warren, 1942, pp. 132–33), the lower two-thirds or three-fourths of the Fairholme member of that formation. Further correlation with the "*Spirifer argentarius* zone" of the Devils Gate limestone (Merriam, 1940, p. 51) of Nevada is suggested. In terms of the standard time column as defined by Cooper *et al.* (1942), the fauna appears to range from upper Finger Lakes stage to lower Chemung stage.

The next succeeding fauna is found in the upper one-fourth of both unit B and the limestone member of the Jefferson and in the dolomite member of the Jefferson and unit A_2. Only the corals are recognizable in the massive dolomite. They include the following.

- *Disphyllum catenatum* Smith
- *Macgeea* sp. cf. *M. solitaria* (Hall and Whitfield)
- *Phillipsastraea* sp. cf. *P. macouni* Smith
- *Tabulophyllum rectum* Fenton and Fenton
- *Thamnophyllum imperfectum* Smith

[5] A detailed report on the brachiopods, by Laird, will appear in the *Journal of Paleontology*.

This indicates correlation with the upper part of the Fairholme member of the Minnewanka formation in Alberta and the lower part of the Palliser member below the "*Cyrtospirifer* zone." Correlation with the "*Pachyphyllum* zone" of the Devils Gate limestone is also suggested. The fauna is strikingly similar to that of the Hackberry shale of Iowa and is probably best referred to a late Chemung to early Cassadaga age as defined by Cooper *et al.* (1942). Precise time relationships of the fauna must wait on further work on Upper Devonian corals in North America.

The next Devonian fauna of Montana is confined to the Three Forks formation. This fauna, fully described by Haynes (1916), is dominated by the brachiopods, *Cyrtospirifer whitneyi*, *Productella coloradoensis*, and *Camarotoechia contracta*, in the calcareous phases; and by the mollusks, *Loxopteria*, *Raymondiceras*, and *Platyclymenia*, in the shales. Brecciation of unit A_2 in northwestern Montana has obscured this fauna, but it may be expected in cores from the upper half of the Potlatch anhydrite in the subsurface. Correlation with the upper part of the Palliser member of the Minnewanka formation of Alberta is clear, as is equivalency to the "*Cyrtospirifer* zone" of the Devils Gate of Nevada.

On the basis of the pelecypods and goniatites, Cooper *et al.* suggest that the Three Forks formation is equivalent to the middle (Conneaut) part of Cassadaga time; however, under normal conditions of non-clastic deposition in the Cordilleran area, the *Cyrtospirifer* fauna apparently persisted nearly to the close of Devonian time. Where sandstones were being deposited, as in the Sappington sandstone member in the Three Forks area, a *Syringothyris* fauna replaced the *Cyrtospirifer* fauna; while the introduction of a black-shale environment was accompanied by the appearance of *Tornoceras* at the close of the period, as in the Exshaw shale of Alberta. In the absence of either of these two special environments, the *Cyrtospirifer* fauna represents latest Devonian time.

PETROLEUM POSSIBILITIES

It is apparent that the search for petroleum reservoirs in the Devonian of Montana has the greatest relative chance for success in the dolomite member of the Jefferson formation and the dolomites of unit A (Potlatch anhydrite), rather than in the dense limestones and shales at the base of the section or the Three Forks formation and equivalent shales at the top.

In outcrop, the saccharoidal dolomites exhibit persistent zones of intercrystalline and fine vuggy porosity with effective porosity ranging from 8 to 16 per cent. Outcrop samples have a superficially permeable appearance, but, on measurement, the permeability is rarely above 15 millidarcys and averages below 10 millidarcys. Microscopic examination of thin sections reveals that the vugs are not connected and that the intercrystalline voids are partly choked with solid hydrocarbon in most samples. Where penetrated by wells on the Sweetgrass arch and adjacent to it, the equivalent lower part of the Potlatch anhydrite contains similar persistent porous zones. Several wells drilled in the Kevin-Sunburst field

to the base of the Potlatch encountered large volumes of gas high in carbon dioxide, and some wells sprayed minor amounts of amber oil. At the same stratigraphic position on Whitlash dome, the Union Oil Company's Mahoney Unit No. 1 (Sec. 22, T. 37 N., R. 4 E., Liberty County, Montana) penetrated a fair thickness of saturated dolomite, but permeability was insufficient for commercial production. Analysis of cores from the saturated zone indicates a porosity of 12 per cent, permeability of 18–26 millidarcys, oil gravity of 32° (J. H. McCourt, 1945, personal communication). In 1946 The Texas Company drilled the Nick Lass No. 2 (Sec. 14, T. 33 N., R. 4 E., Liberty County, Montana) through a reported thickness of 1,190 feet of Devonian. Sweet gas, estimated at 18 million cubic feet per day, was encountered in the Potlatch (Unit A) between 230 and 250 feet below the top of the Devonian. Nitrogen, measured at 620,000 cubic feet per day, was encountered in an 11-foot zone in Unit B (John E. Blixt, 1946, personal communication). Recently The Texas Company completed as a dry hole its Unit No. 1–822 on Bowdoin dome (Sec. 8, T. 32 N., R. 32 E., Phillips County, Montana), reporting top of Three Forks at 3,992 feet, top of Jefferson at 4,075, top of Ordovician at 5,095, and top of Cambrian 5,645 feet. Commerical quantities of oil are produced from a porous zone in the Potlatch in the Princess field of south-central Alberta, and the Imperial Oil Company has recently announced discovery of substantial production from the Devonian in its Leduc No. 1 (Sec. 22, T. 50 N., R. 26 W., 4th M.) near Edmonton, Alberta. Encouraging showings have also been encountered in the Devonian of the Ram River area in the central Alberta foothill belt.

The scanty data now available do not permit a proper evaluation of the potentialities of the Devonian dolomites, but it seems safe to state that their normally occurring primary porosity and permeability do not reach high productive levels, excepting locally and unpredictably. Therefore, it is reasonable to consider atypical depositional conditions which may have induced greater primary reservoir characteristics, and to seek areas where post-depositional effects may have substantially increased porosity and permeability. A suggestion of atypical conditions is found in outcrops in the Big Snowy Mountains, where, near the top of the dolomite member of the Jefferson, there is a minor but fairly persistent reef facies—a highly porous zone composed almost entirely of loosely cemented coral and algal fragments. Since this facies is inconspicuous west and north of the Big Snowy Mountains, it seems possible that its development reflects approach to the margin of the basin of Devonian deposition which lies an undetermined distance east and south. Predicting the position of maximum reef development in this ill defined area is impossible with the present lack of data, but the potentialities should not be overlooked.

Secondary increase of porosity and permeability in the dolomites may result from fracturing or from enlargement and interconnection of pore spaces by weathering or ground-water percolation. Fracturing might be locally important, but would require a "seeing-eye" drill-bit for successful exploitation. The second

possibility would require pre-Mississippian emergence. In this connection, it can be demonstrated that no such emergence of sufficient magnitude to affect the dolomites took place over most of the area. However, the southeastern margin of distribution may again provide an exception. It is possible that, near the edge of the basin, removal or non-deposition of the Three Forks formation exposed the dolomites to pre-Mississippian solution; but, as stated previously, the edge of the depositional basin has yet to be defined by drilling. Nevertheless, there is the possibility of the occurrence of dolomites with secondarily enhanced reservoir characteristics, or porous reef-limestones, directly beneath the black shales of the basal Mississippian.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 8 (AUGUST, 1947), PP. 1431-1453, 8 FIGS.

OREGON BASIN FIELD, PARK COUNTY, WYOMING[1]

PAUL T. WALTON[2]
Casper, Wyoming

ABSTRACT

The Oregon Basin oil and gas field is in north-central Wyoming on the western margin of the Big Horn basin, a closed Tertiary-filled structural basin. Adjacent to the synclinal axis of the asymmetrical Big Horn basin, Oregon Basin is a large anticline having 1,600 feet of closure. Transverse tensional and shear faulting is present along the axis, both in the surface and subsurface strata. The oil and gas accumulation is present primarily because of this structural trap. The anticline is divided into two domes separated by a low saddle which is considered unproductive.

The folding responsible for the present structural configuration began in late Upper Cretaceous time. Subsequent movement has occurred during the Tertiary.

The most highly developed and important production is black, 20°–22° gravity oil from the Permian Embar limestone and the Pennsylvanian Tensleep sandstone. This productive area occupies only 40 per cent of the total area within the closing contour. Black, 18° gravity oil is also produced from the Mississippian Madison limestone. Commercial amounts of gas occur in the Cretaceous Frontier and Cloverly sandstones and the Triassic Chugwater sandstones. Gas is present in commercial quantities both separately and in association with the oil in the Embar limestone. Oregon Basin is one of the more important reserves of black oil in Wyoming, having an estimated ultimate production in excess of 150,000,000 barrels.

A well on the south dome has penetrated a normal sequence of strata from the surface to the pre-Cambrian granite. No production was found below the presently known Madison oil zones. A non-commercial showing of light paraffine-base oil was found in the basal Cambrian Flathead sandstone. The limits of the present production have been mostly defined and little exploratory drilling is foreseen for the future.

INTRODUCTION

The Big Horn basin of north-central Wyoming is the most prolific black-oil province in the state (Fig. 1). Being a basin formed in late Upper Cretaceous time, the Big Horn in its present configuration is a closed structural basin, filled with Paleocene and Eocene continental sedimentary rocks. During the uplift of the contiguous mountain masses and the downsinking of the central part of the basin numerous *en échelon*, asymmetrical anticlines were formed around its periphery and a few out in the basin itself. Many of these anticlines became traps of migrating petroleum and are now oil fields.

Oregon Basin is a large topographic depression occupying the crest of a north-trending anticline on the west side of the Big Horn basin (Fig. 2). The Oregon Basin field is in reality two oil fields which occupy two distinct, closed domes (north and south) on the same anticlinal axis. Having an estimated total reserve in excess of 150,000,000 barrels in the three producing formations, the Permian Embar limestone, the Pennsylvanian Tensleep sandstone, and the Mississippian Madison limestone, Oregon Basin is one of the more important oil fields of the Rocky Mountain area.

[1] Manuscript received, April 12, 1947. Published by permission of the Pacific Western Oil Corporation.

[2] Division geologist, Rocky Mountain division, Pacific Western Oil Corporation. The writer wishes to thank The Ohio Oil Company, The Texas Company, and the Husky Refining Comapny for making their well logs available for this paper.

HISTORY

To test the impressive surface expression of the anticlinal folding, a shallow well was drilled in 1912 by the Enalpac Oil and Gas Company on the south dome in the N.W. $\frac{1}{4}$, S.W. $\frac{1}{4}$ of Sec. 32, T. 51 N., R. 100 W., discovering a gas flow of 20 million cubic feet per day from the Lower Cretaceous Cloverly sandstone.[3] Subsequent drilling in 1916 by the same company on the north dome in the SE. $\frac{1}{4}$,

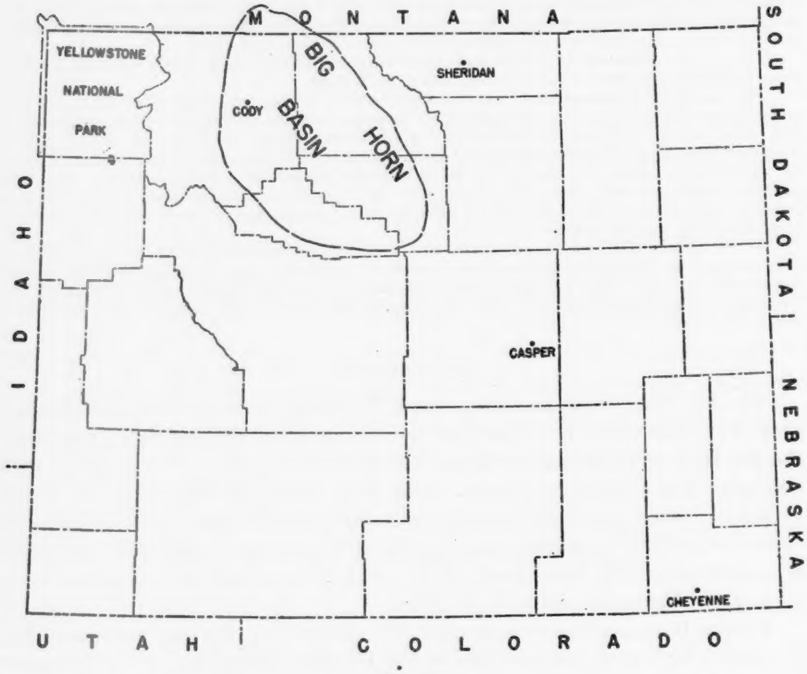


FIG. I
INDEX MAP, BIG HORN BASIN, WYOMING

NW. $\frac{1}{4}$ of Sec. 5, T. 51 N., R. 100 W., revealed gas in the Cloverly, and a well in the NE. $\frac{1}{4}$, NW. $\frac{1}{4}$ of Sec. 8 found gas in a sand in the Jurassic Morrison formation. In March, 1927, in a well drilled by the Ohio Oil Company, on the north dome, in the NW. $\frac{1}{4}$, NE. $\frac{1}{4}$ of Sec. 8, oil was discovered in the Embar limestone and the Tensleep sandstone from 3,354 to 3,650 feet in depth. The well flowed

[3] R. D. Espach and H. D. Nichols, "Petroleum and Natural Gas Fields in Wyoming," *U. S. Bur. Mines Bull. 418* (1941), pp. 71–73.

initially 800 barrels of 22° A.P.I. gravity black oil daily. This discovery marked the beginning of the field's importance as an oil and gas producer. Subsequent drilling has revealed gas in the Chugwater formation in a well in the SW. ¼,

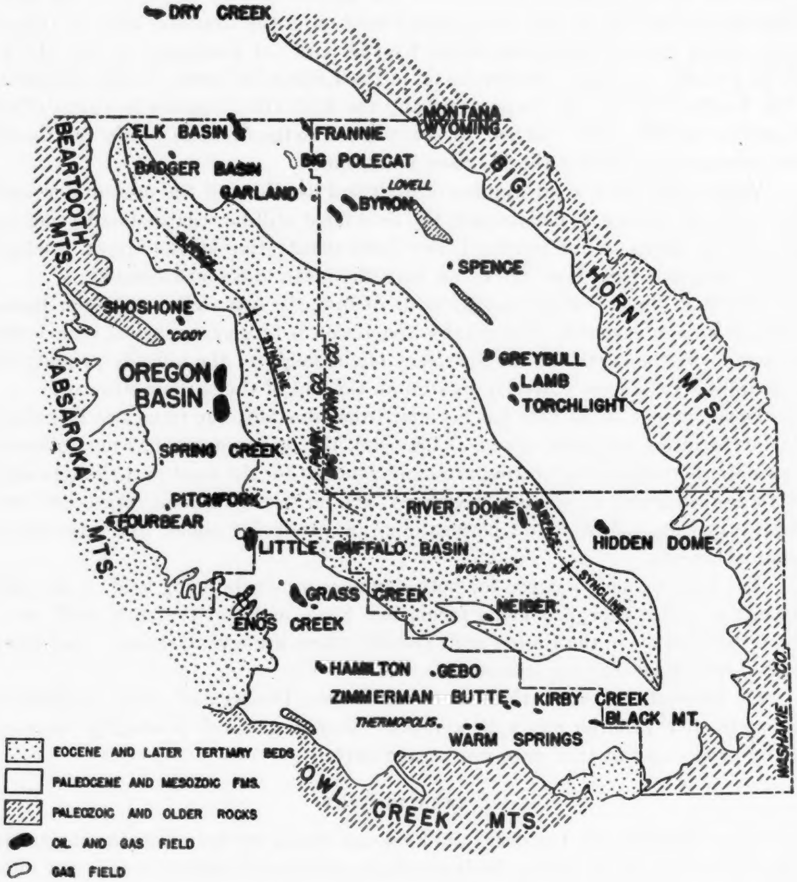


FIG. 2

MAP OF BIG HORN BASIN

SHOWING LOCATION OF OREGON BASIN FIELD

NE. ¼ of Sec. 32, north dome. In 1929 a well in the SE. ¼, SE. ¼ of Sec. 6, north dome, produced initially 6 million cubic feet of gas per day from the Embar limestone. On an upthrown fault block in the south end of the south dome a well

drilled in 1934 in the NW. corner of Lot 2, Sec. 9, produced initially 7.6 million cubic feet of gas per day from the Frontier formation. The Yale Oil Company in 1943 completed a well in the NW. ¼, NE. ¼ of Sec. 5, south dome, in the Madison limestone which produced in excess of 400 barrels of 16.5° gravity oil per day. Subsequent drilling on the north dome found oil in the Madison also. In 1944 a well drilled on the south fault block by the Kirk Oil Company, in the SE. ¼, NW. ¼ of Sec. 9, found commercial oil in the Embar, but water in the Tensleep. The Pacific Western Oil Corporation and the Kirk Oil Company in 1945 drilled a well in the SW. ¼, SE. ¼ of Sec. 29, south dome, to the Archean granite but found no commercial oil below the Madison limestone.

While there are a great number of undrilled locations, if the present one well per 40-acre spacing is maintained, the field must still be regarded as having its productive limits well determined. Dry holes penetrating all the known productive formations have been drilled on both the north and south domes.

Although the conditions incidental to drilling the first wells on Oregon Basin are not known in detail, a reasonable conclusion is to give geological knowledge of some sort the credit for the discovery of the field, for the initially productive gas and oil wells were correctly located on the top of the surface structure.

Development of the field has been far from constant, due to lack of transportation facilities, markets, *et cetera*. Likewise, the development has not followed optimum petroleum engineering principles, so that for the most part there is very little known about such basic reservoir characteristics as gas-oil ratios, bottom-hole pressures, porosity and permeability of producing zones, and edge-water encroachments.

The basic spacing pattern for both domes is presently being held to one well per 40 acres for each producing formation. Since many of the early wells were dual completions in the Embar and Tensleep there are several instances of spacings down to one well per 10 acres.

On December 1, 1946, there were 146 Embar-Tensleep oil wells, 5 Madison oil wells, one Frontier gas well, and one Cloverly gas well producing. Average daily production at that date was 10,490 barrels.

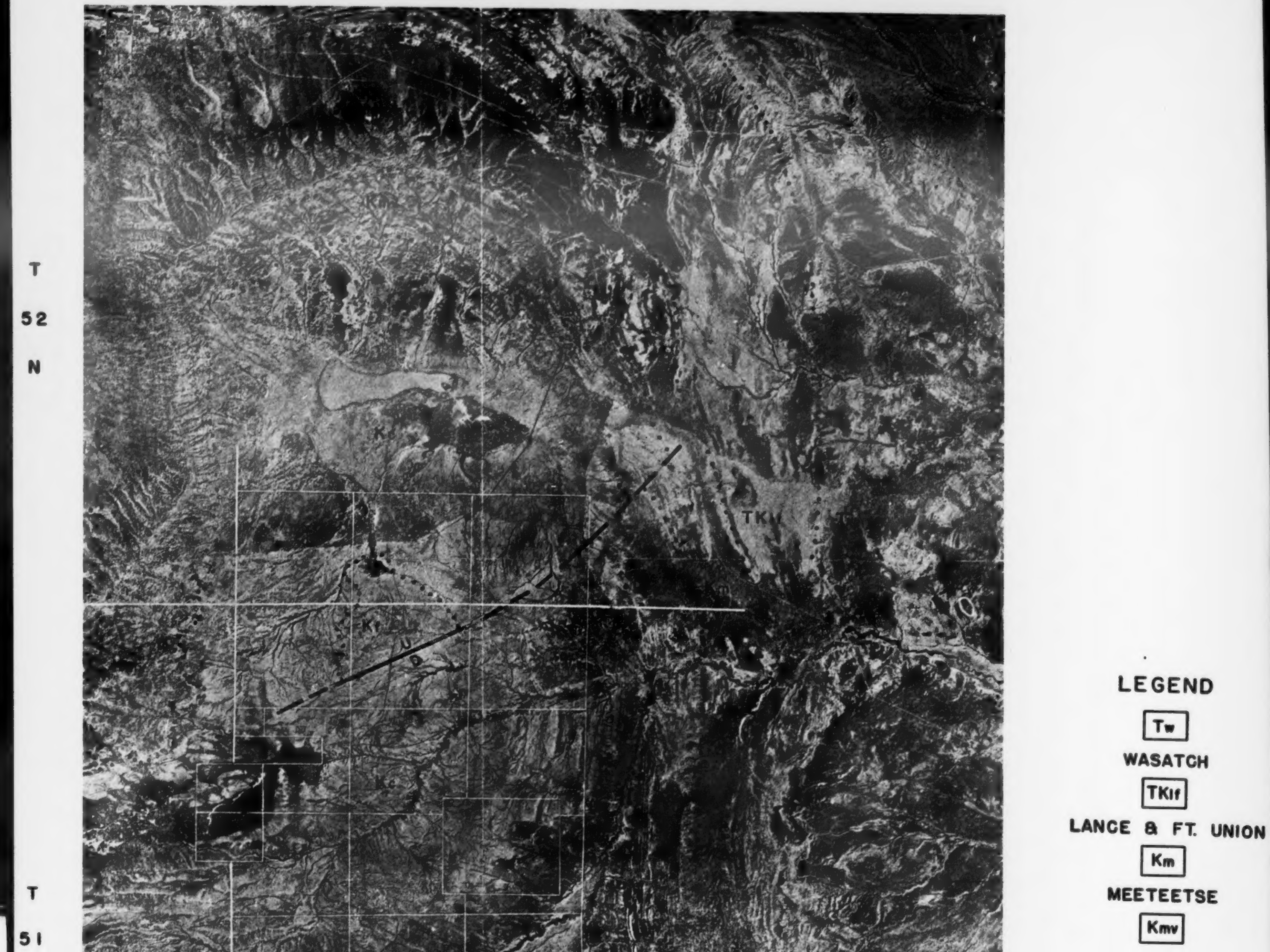
STRATIGRAPHY

Upper Cretaceous, Paleocene, and Eocene strata are found on the surface in the vicinity of Oregon Basin. Beds ranging in age from Cambrian to Upper Cretaceous have been penetrated by a well drilled to the Archean granite in the SW. ¼, SE. ¼ of Sec. 29 on the south dome. In addition, the same rocks are exposed along the Shoshone River, a few miles northwest, where detailed surface studies have been made. Recent papers by Johnson,[4] Pierce and Andrews,[5] and Stipp,[6] contain

[4] G. Duncan Johnson, "Geology of the Mountain Uplift Transected by the Shoshone Canyon, Wyoming," *Jour. Geol.*, Vol. 42, No. 8 (1934), pp. 814–23.

[5] W. G. Pierce and D. A. Andrews, "Geology and Oil and Coal Resources of the Region South of Cody, Park County, Wyoming," *U. S. Geol. Survey Bull. 921 B* (1941), pp. 108–40.

[6] T. F. Stipp, "Paleozoic Formations near Cody, Park County, Wyoming," *Bull. Amer. Petrol. Geol.*, Vol. 31, No. 2 (February, 1937), pp. 274–81.


T
52
N
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Km
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Km
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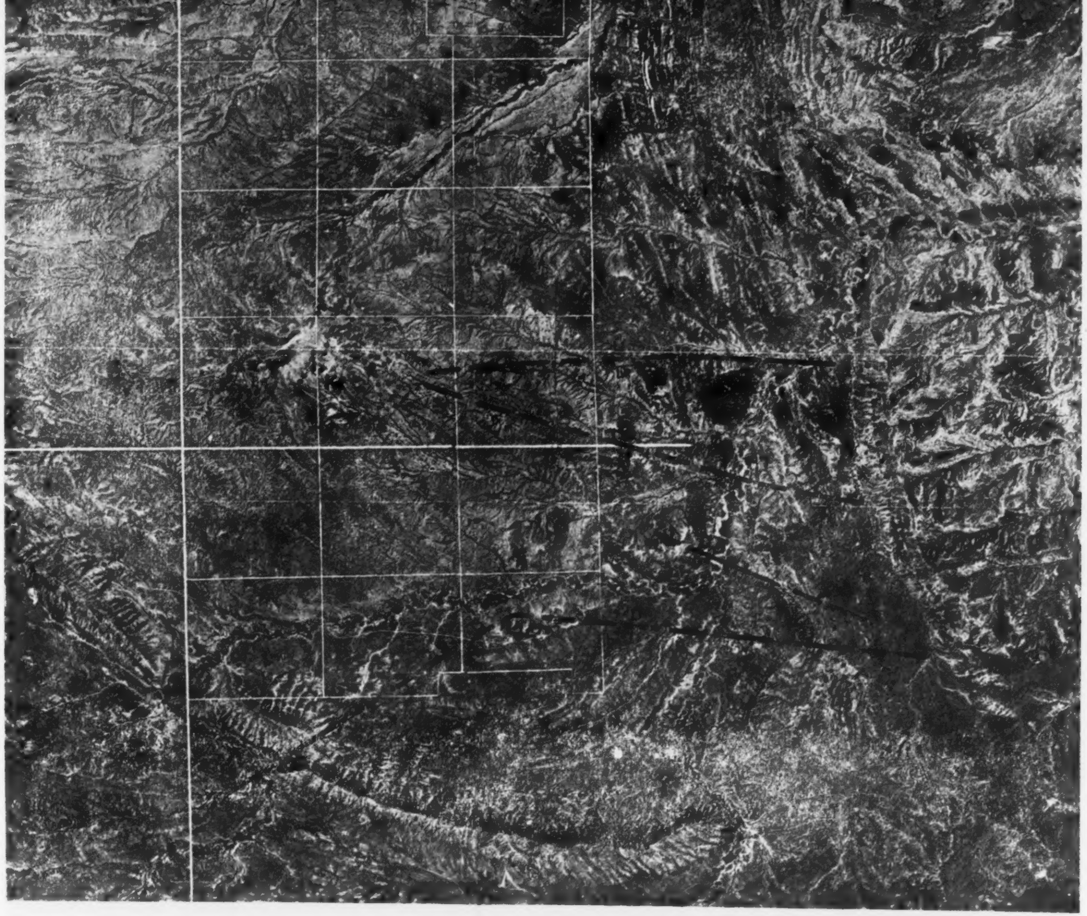


T
50
N

MEETEETSE

Kmv
MESAVERDE

Kc
CODY

Kf
FRONTIER

R 101 W

R 100 W

FIG. 3
OREGON BASIN OIL FIELD
PARK COUNTY, WYOMING
PAUL T. WALTON
3-15-47

FIG. 4

references to all the older work in the area, and in addition describe and redefine certain stratigraphic units.

SURFACE FORMATIONS

TERTIARY

Wasatch formation.—Representing a deposit from streams flowing on a wider spread peneplain, this formation is discordant and unconformable with all olde- strata. It plainly overlaps the Paleocene Fort Union, and Upper Cretaceous Lance formations on the east flank of Oregon Basin (Fig. 3).[7] Being characterized by brown and buff coarse, conglomeratic sandstones interbedded heterogeneously with pastel pink, green, and gray mudstone, the Wasatch is easily identified at outcrops. Thicknesses up to 1,300 feet have been measured nearby.

PALEOCENE AND UPPER CRETACEOUS

Fort Union and Lance formations.—Due to their similar lithologic character and obscure relationship on the east flank of Oregon Basin, these two formations are shown as one outcrop unit on the aerial mosaic (Fig. 3). Each is composed of continental or brackish-water deposits consisting primarily of buff sandstone and drab shale. Hewett[8] differentiates these two sequences mainly on the absence of red shale in the Lance. Thicknesses of the Paleocene Fort Union of 5,600 feet have been measured, and the Upper Cretaceous Lance attains a thickness of 1,800 feet in the Oregon Basin vicinity.

The Fort Union is unconformable with the Lance, and the base of the formation is usually drawn on a conglomeratic sandstone which appears to overlap the beds of the Lance. The Lance is concordant with the underlying Meeteetse formation, and probably the contact is gradational, that is, the Lance represents a sandy facies of the brackish-water deposits being laid down at the end of Montana time. Apparently this area was a considerable distance west of the shoreline of the late Montana sea, for no evidence of the presence of deposits which might be properly correlated with the marine Fox Hills sandstone has been found.

UPPER CRETACEOUS

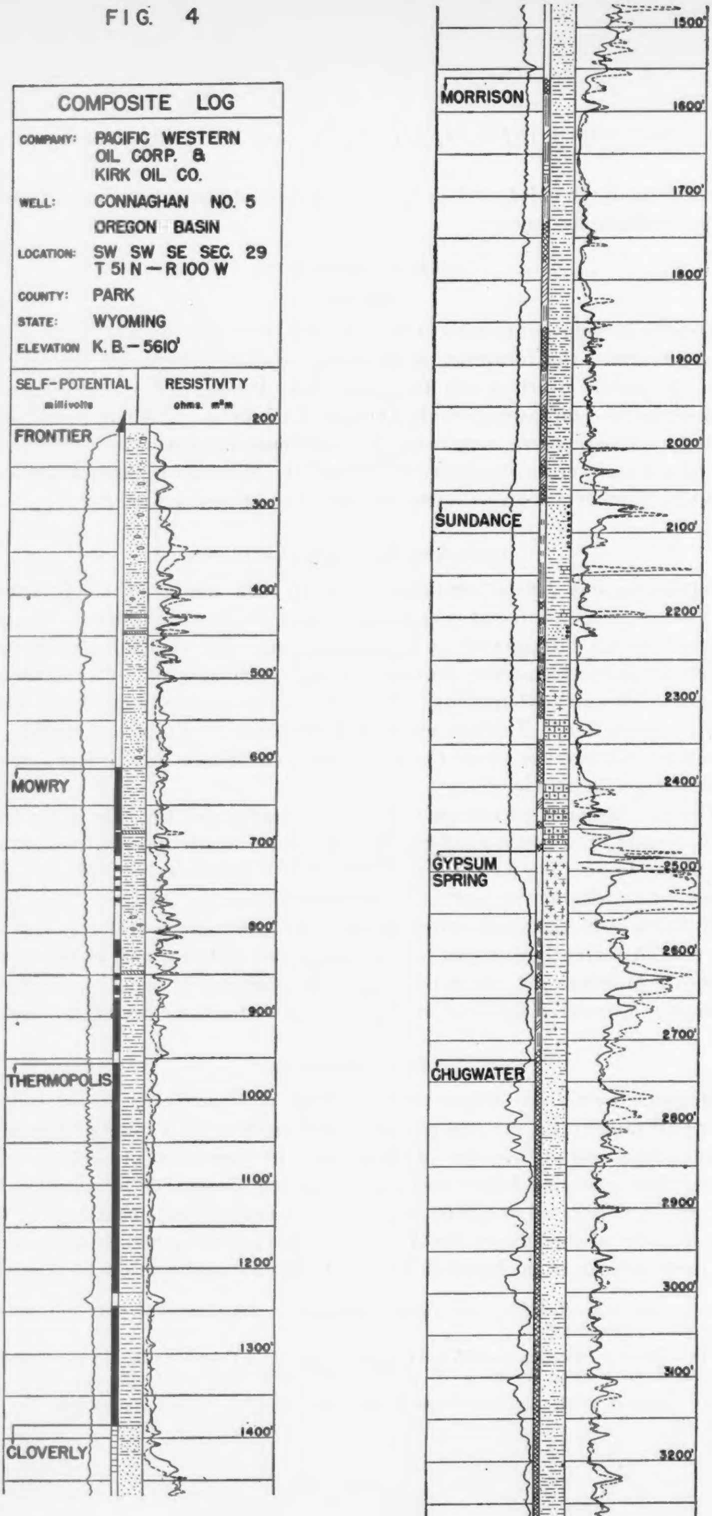
Meeteetse formation.—These strata consist of thinly interbedded brackish-water buff sandstones, gray mudstones, and lignitic coal. Named by Hewett[9] for its good exposures at the town of Meeteetse, this formation presents a contrast between the overlying Lance and the underlying Mesaverde formations. Being only slightly indurated, the Meeteetse is readily eroded, and forms a strike valley on three sides of the Oregon Basin anticline. Representing mainly a fine-grained clay or mud facies of the brackish-water late Montana deposition, this formation

[7] A mosaic constructed by the writer from aerial photographs taken by Aero Service Corporation, Philadelphia, Pennsylvania.

[8] D. F. Hewett, "Geology and Oil and Coal Resources of the Oregon Basin, Meeteetse, and Grass Creek Basin Quadrangles, Wyoming," *U. S. Geol. Survey Prof. Paper 145* (1926), pp. 26–40.

[9] D. F. Hewett, "The Shoshone River Section, Wyoming," *U. S. Geol. Survey Bull. 541* (1912), pp. 91, 102.

FIG. 4


COMPOSITE LOG
COMPANY: PACIFIC WESTERN OIL CORP. & KIRK OIL CO.
WELL: CONNAGHAN NO. 5
OREGON BASIN
LOCATION: SW SW SE SEC. 29 T 51 N — R 100 W
COUNTY: PARK
STATE: WYOMING
ELEVATION K. B. — 5610'
SELF-POTENTIAL millivolts
RESISTIVITY ohms. m²m
FRONTIER
MOWRY
THERMOPOLIS
CLOVERLY
MORRISON
SUNDANCE
GYPSUM SPRING
CHUGWATER
200'
300'
400'
500'
600'
700'
800'
900'
1000'
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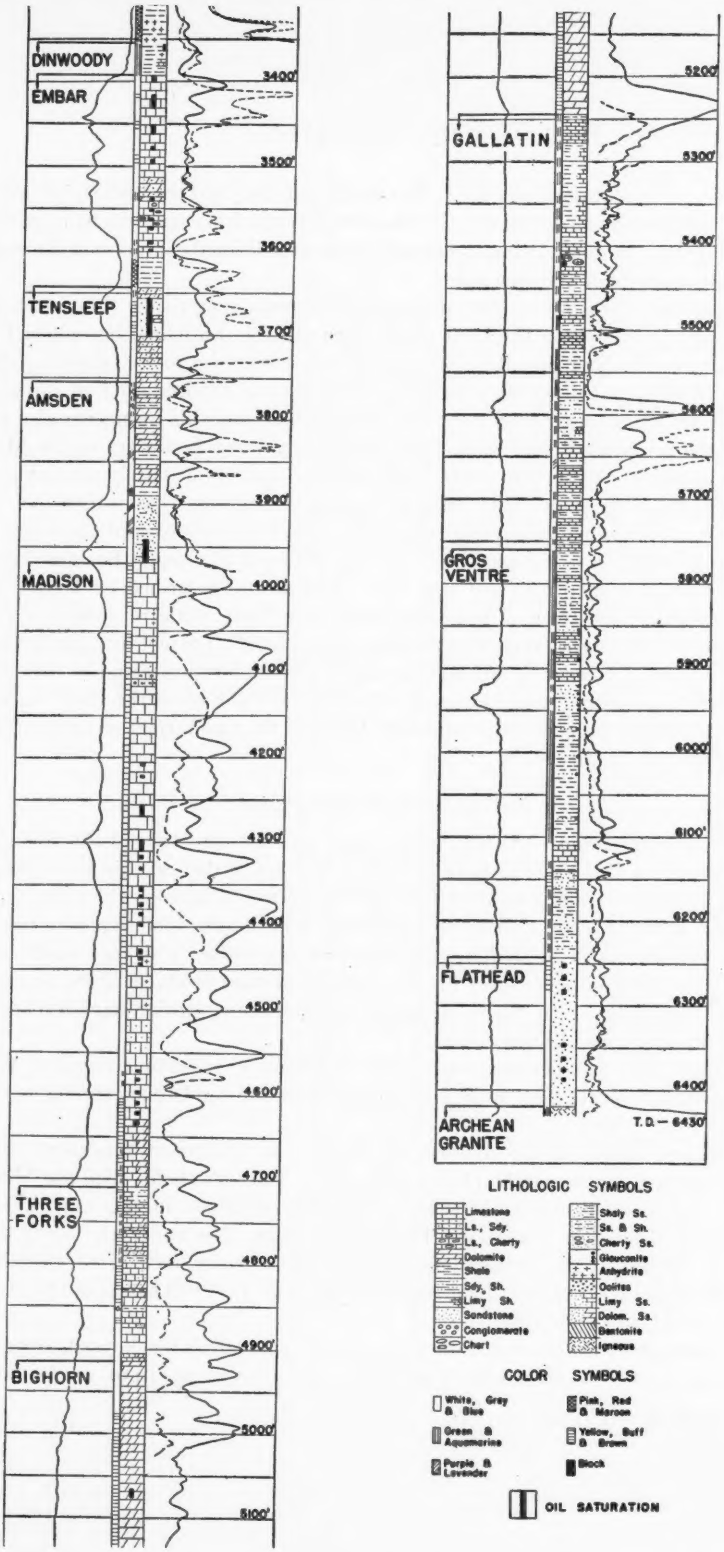
DINWOODY
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GALLATIN
GROS VENTRE
FLATHEAD
ARCHEAN GRANITE
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5800'
5900'
6000'
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6300'
6400'
T.D. — 6430'
LITHOLOGIC SYMBOLS
Limestone
Ls., Sdy.
Ls., Cherty
Dolomite
Shale
Sdy. Sh.
Limy Sh.
Sandstone
Conglomerate
Chert
Shaly Ss.
Ss. & Sh.
Cherty Ss.
Glauconite
Anhydrite
Oolites
Limy Ss.
Dolom. Ss.
Bentonite
Igneous
COLOR SYMBOLS
White, Grey & Blue
Pink, Red & Maroon
Green & Aquamarine
Yellow, Buff & Brown
Purple & Lavender
Black
OIL SATURATION

probably is gradational with both the overlying Lance and the underlying Mesaverde. Observed thicknesses of the Meeteetse range from 600 feet to 1,350 feet, the difference no doubt being due largely to the transitional character of the upper and lower limits of the formation.

Mesaverde formation.—The massive sandstones comprising this formation have been eroded from the crest of the Oregon Basin anticline, but where they crop out on its flank they form a large and impressive rim rock nearly encircling the field (Fig. 3). Consisting principally of a 1,200-foot thickness of buff and white sandstone interbedded with gray and brown mudstone, this formation also contains the commercial coal beds of the region. The lower boundary of the Mesaverde is placed at the base of the thick massive sand immediately overlying the soft marine Cody shale. This contact is a facies line rather than a time line, and migrates up through the section toward the east and down toward the west.

Cody shale.—The topographic "low" on the crest of Oregon Basin is formed on the easily eroded marine Cody shale. Named and described by Hewett[10] at outcrops near the town of the same name, the Cody shale represents a thick marine deposit of gray clay. Thicknesses ranging from 2,150 feet to 3,200 feet have been observed in near-by exposed sections. The underlying Frontier formation represents a regional sandy facies of deposition at the base of the Cody shale, so that in a given large area the boundary between the two formations migrates up and down stratigraphically.

SUBSURFACE FORMATIONS

Frontier formation.—Although the upper massive sandstone of this formation is exposed on the crests of both the north and south domes, this same massive sand is commercially productive of gas in the fault block on the south end of Oregon Basin (Fig. 6). Essentially consisting of an interbedded sequence 490–600 feet in thickness of lenticular, gray, massive sandstones and gray sandy shale containing bentonite beds, the Frontier is an important producer of gas and green oil in other fields of the Big Horn basin. Unfortunately, erosion has breached the Frontier reservoir at Oregon Basin.

Black chert pebbles commonly occur in the upper sandstone member. White feldspar and black chert grains are common in the sandstones throughout the formation.

Mowry shale.—Lying conformably below the lowermost sandstone of the Frontier is a sequence of black and gray, platy, siliceous shale called the Mowry. Fish scales and bentonite beds are commonly contained in this unit which is gradational into the underlying Thermopolis shale. The upper and lower limits of the Mowry, being transitional, are placed at easily recognized electric-log correlations rather than at lithologic changes (Fig. 4). Thicknesses of the Mowry vary from 310 to 360 feet.

Thermopolis shale.—Predominantly, the Thermopolis is black, fissile shale containing thin beds of bentonite. A persistent sandstone member 150–170 feet above

[10] D. F. Hewett, *op. cit.*, pp. 15–18.

its base is called the Muddy (Fig. 4). The Thermopolis averages 430 feet in thickness.

LOWER CRETACEOUS

Cloverly formation.—Underlying the Thermopolis is a 180-foot sequence of light buff, sandy siltstone, gray shale and light gray, clean quartz sandstone, probably marine or littoral in origin. Maroon and green clay shale underlie the lower massive sandstone (Fig. 4). The interpretation of Hewett[11] and Pierce and Andrews[12] in which the sandstones are called Cloverly and the maroon and green shales placed in the Jurassic Morrison formation is followed herein. It is acknowledged that workers in near-by areas may not be in agreement with this correlation.

The initial gas discovery at Oregon Basin was made in the basal Cloverly sandstone.

UPPER JURASSIC

Morrison formation.—Recognized throughout the Rocky Mountain area as a flood-plain deposit of vast extent, the Morrison formation is represented in Oregon Basin by a 480–515-foot sequence of interbedded green, gray, lavender, pink, and maroon mudstone and shale containing, here and there, thin lenses of conglomeratic sandstone and gray limestone concretions. One of these lenticular sands made a short-lived gas well on the north dome in the NE. $\frac{1}{4}$, NW. $\frac{1}{4}$ of Sec. 8.

The lower boundary of the Morrison is marked by the green glauconitic sandstones of the Sundance formation which represent an abrupt change in sedimentation.

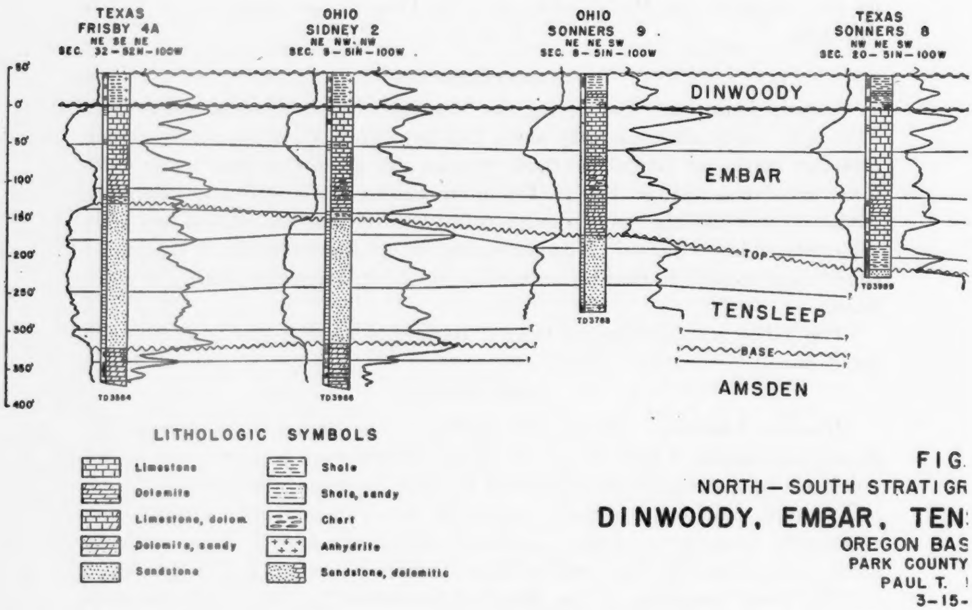
Sundance formation.—Characteristically this formation is composed of three members (Fig. 4). The upper is a sequence of green glauconitic sandstones; the middle member consists of green calcareous shale; the lower member comprises a pink, lavender, maroon, and purple mudstone and shale section in which thin beds of gray and buff oölitic limestone and white anhydrite occur. The lower boundary of the Sundance is placed below the oölitic limestones and at the top of the thick bed of massive, white anhydrite, herein referred to the Gypsum Spring formation in accordance with Love's[13] work in the Wind River basin. The Sundance, defined as such, has an average thickness of 410 feet in Oregon Basin.

Gypsum Spring formation.—The massive, white, 80-foot anhydrite bed at the top of this formation makes an excellent lithologic and electric-log marker in Oregon Basin (Fig. 4). The lower part of the Gypsum Spring consists of maroon, lavender, and green mudstones with some thin beds of white anhydrite. An average thickness of 240 feet occurs on the south dome. The lower boundary of the Gypsum Spring formation is marked by the profound disconformity at the base of the Upper Jurassic. In the northern Rocky Mountain region, this discon-

[11] D. F. Hewett, *op. cit.*, pp. 12–13.

[12] W. G. Pierce and D. A. Andrews, *op. cit.*, pp. 116–19.

[13] J. D. Love, "Geology along the Southern Margin of the Absaroka Range, Wyoming," *Geol. Soc. America Spec. Paper 20* (1939), p. 45.



formity brings the base of the Upper Jurassic in contact with rocks Triassic, Permian, Pennsylvanian, and Mississippian in age.

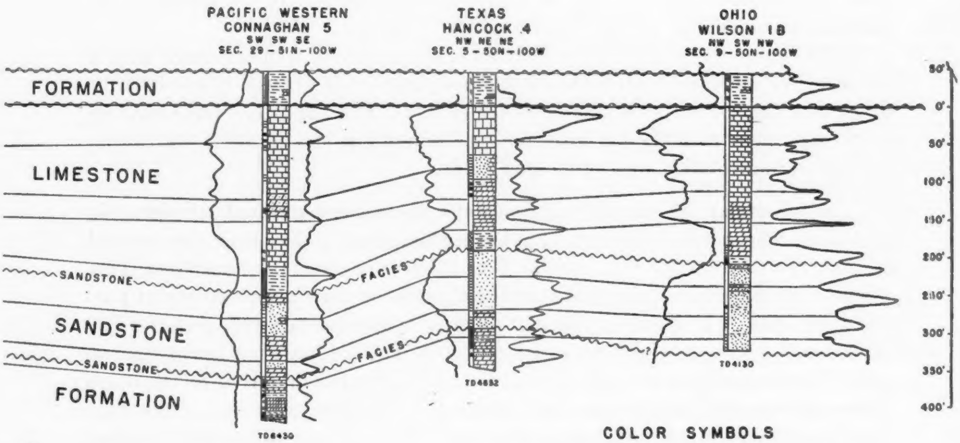
TRIASSIC

Chugwater formation.—Pink and salmon-colored fine-grained sandstones and siltstones interbedded with maroon shale and mudstone characterize the Chugwater which averages 625 feet in thickness on the south dome. On the north dome a sand in the upper part of the formation produced commercial gas for a short time in a well in the SW. $\frac{1}{4}$, SW. $\frac{1}{4}$ of Sec. 33, and in another in the SW. $\frac{1}{4}$, NE. $\frac{1}{4}$ of Sec. 32.

The basal part of the Chugwater contains thin beds of maroon mudstone and fine sandstone impregnated with pink anhydrite. These strata grade downward into the white anhydrite interbedded with green shale which represents the Dinwoody formation.

Dinwoody formation.—The Dinwoody formation consists of a marine or estuarine facies of pyritic green shale and white anhydrite which intertongues with the base of the Chugwater. Maroon shale tongues of the Chugwater are present in the Dinwoody in some wells in Oregon Basin. Intertonguing of the Chugwater, Dinwoody, and Embar (Phosphoria) has been noted in southern Wyoming by Thomas.[14]

[14] H. D. Thomas, "Phosphoria and Dinwoody Tongues in Lower Chugwater of Central and Southeastern Wyoming," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 12 (December, 1934), pp. 1655–98.



5
'APHIC CROSS SECTION
SLEEP, AMSDEN ZONES
SIN FIELD
', WYOMING
WALTON
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The abrupt color change in the well cuttings as the bit goes from the Chugwater redbeds into the green Dinwoody shale is a valuable marker for geologists in selecting casing points. Depending mainly on the personal choice involved in recognizing its top, the thickness of the Dinwoody averages 30–45 feet in Oregon Basin.

PERMIAN

Embar limestone.—Immediately below the Dinwoody formation is an interbedded sequence of gray, finely crystalline, vuggy limestone and light bluish gray dolomite which is called the Embar limestone throughout the Big Horn basin. Although the name Embar was originally given by Darton[15] to all the beds between the base of the Chugwater and the top of the Tensleep sandstone, which interval is now recognized as consisting of both Triassic and Permian strata, it is herein strongly suggested that the term Embar is too well established among geologists and oil men to consider abolishing it when it is applied in its present usage; that is, when it is used to denote only the characteristic limestone section usually correlated with the Phosphoria formation of Idaho.

The Embar limestone is marine in origin, and it is presently the main oil-producing formation of Oregon Basin. Commonly it consists of well saturated, coarsely crystalline, porous limestone interbedded with hard, dense, barren lime-

[15] N. H. Darton, "Geology of the Bighorn Mountains," *U. S. Geol. Survey Prof. Paper 51* (1907), p. 35.

stone and dolomite streaks. The oil is considered indigenous to the Embar. Considerable porosity, due to vertical fracturing, is present.

A thin zone of gray to yellow sandstone, commonly so well cemented with a limestone or dolomite matrix that it has no porosity, is present intermittently 65–75 feet below the top of the limestone (Fig. 5). This sandstone represents an eastward tongue of a blanket sandstone in comparable stratigraphic position in the region immediately west of Oregon Basin.

The lower part of the Embar limestone poses some unusual stratigraphic problems. The north-south stratigraphic section (Fig. 5) has been constructed to show the relationship between the Embar limestone and the underlying Tensleep sandstone. If it is assumed that the electric-log correlations represent paralel time lines, it is apparent that the limestone-sandstone contact or facies line migrates down the section from north to south. The red shale marker at the top of the Tensleep sandstone and a part of the typical Embar limestone on the south dome are unquestionably equivalent in age to the upper 50–75 feet of the Tensleep sandstone on the north dome. Since the Embar is assigned to the Permian, and the Tensleep to the Pennsylvanian, several questions arise. Is the upper part of the Tensleep on the north dome Permian or is the lower part of the Embar on the Embar on the south dome Pennsylvanian in age?

Another point needing clarifying is the following. It is known that the Embar limestone is thinning regionally toward the north. Is this thinning due to truncation or non-deposition as has commonly been considered, or is it due to a change of facies whereby the Tensleep sand replaces the limestone of the Embar? A cursory comparison of the electric and sample logs of several Elk Basin and Oregon Basin wells reveals a definite indication that the Tensleep sand has replaced all but a small part of the Embar limestone at Elk Basin.

PENNSYLVANIAN

Tensleep formation.—The most important oil reserve at Oregon Basin is in the Tensleep sandstone. Its relationship with the overlying Embar limestone is apparently transitional, and the top of the sandstone facies does not mark a time line (Fig 5). Likewise the Tensleep sandstone is laterally gradational into a gray, sandy dolomite facies which may replace nearly all the sandstone. This transition occurs mostly on the south dome and may represent all stages between a sandstone with a dolomitic cement to a pure dolomite. The oil productivity of the Tensleep is dependent on the net thickness of porous sandstone so that in local areas in the field, where dolomite has replaced much of the sandstone, the oil yield will be markedly decreased.

The Tensleep is considered a marine deposit, and is composed of fine-grained well sorted, clear quartz grains. Typically it also contains a few large, spherical, frosted quartz grains. The top 20 feet shows steep torrential-type cross-bedding, but its lower parts are massively bedded. The oil in the Tensleep is considered by many geologists to have migrated from the Embar.

The lower boundary of the Tensleep is usually placed at the first occurrence of

red and lavender dolomite or shale, which is considered the top of the Amsden formation. Detailed study of the lower part of the Tensleep (Fig. 5) indicates a transitional nature like that observed in the upper part. From north to south, the base of the Tensleep sandstone facies migrates downward across time lines, so that, at the south end of Oregon Basin, the lowermost 30–40 feet of the Tensleep is equivalent to the uppermost 20–30 feet of Amsden formation on the north dome. The Tensleep sandstone from these data (Fig. 5) appears to be a large sandstone lentil whose deposition began in lower Pennsylvanian time, and continued into the Permian. The boundaries of this lentil are facies lines which transect time lines.

The net thickness of the sandstone facies of the Tensleep in Oregon Basin varies from 20 feet on the south dome to 190 feet on the north dome.

Amsden formation.—This formation consists of two distinct members in Oregon Basin, each about the same in thickness (Fig. 4.)The upper member comprises a sequence of gray, green and lavender-tinted, massive dolomite interbedded with lavender and red shales and white anhydrite. The lower member is dominately gray, clear, porous quartz sandstone cut by thin beds of lavender and maroon mudstone and siltstone. At least 20 feet of this sandstone are well saturated with oil on the crests of both domes, but no production has ever been realized from it due to lack of permeability or formation pressure.

The Amsden averages 210 feet in thickness on the south dome. The basal sandstone of the Amsden rests on a regional unconformity; that is, the eroded surface of the top of the lower Mississippian Madison limestone. No dip discordance can be seen above and below this erosion surface, even though beds of middle and upper Mississippian intertongue between the Amsden and Madison a short distance north.

LOWER MISSISSIPPIAN

Madison limestone.—Porous zones in the lower 500 feet of the Madison are important producers of oil in Oregon Basin and elsewhere. Being essentially a massive limestone averaging 740 feet in thickness, the Madison is a marine deposit of great magnitude. The porosity in the better producing zones is apparently due to pore space between the individual calcite crystals and to vugs. In the lower parts of the Madison partial dolomitization is mostly the cause for the porosity. Individual zones of porosity can not be correlated from well to well, but there is fair correlation of the aggregate zones between wells. The oil in the Madison is considered indigenous to the formation by most geologists.

The lower boundary of the Madison is marked by the Devonian limestone shales and sandstones. The contact is considered conformable.

DEVONIAN

Three Forks formation.—Strata equivalent to the 205 feet of interbedded limestone, green shale, and calcareous sandstone in the Connaghan well No. 5 (Fig. 4), which are herein called Three Forks, have been described from near-by out-

crop sections by Johnson[16] and Stipp.[17] Correlation between these beds and the Three Forks formation has been solely on the basis of lithologic character. Stipp[18] has identified a fossil indigenous to the middle Devonian Jefferson limestone in the lowest part of the beds herein called Three Forks, but no attempt to differentiate between Jefferson and Three Forks is here made.

Since no Silurian beds are known in this area, the contact between the Three Forks and the underlying Ordovician Big Horn dolomite is unconformable.

ORDOVICIAN

Big Horn dolomite.—The massive, buff, porous, and vuggy Big Horn dolomite attains an approximate thickness of 330 feet in the Connagban No. 5 (Fig. 4), depending on the interpretation of its upper and lower contacts. Some brown oil stains were observed but tests showed only black carbonaceous water. As the Big Horn is considered a marine deposit, the occurrence of fresh "swamp" water was surprising.

The base of the Big Horn is marked by the dark green shale and limestone of the Cambrian Gallatin formation.

CAMBRIAN

Gallatin formation.—The dark green platy shales and glauconitic limestones of the Gallatin are a striking contrast to the Big Horn dolomite. Some beds of dark gray, platy shale and a sedimentary breccia composed of gray limestone and dark gray shale are present. In the lower part of the Gallatin there is a sequence of finely interbedded, dark green micaceous shale, clear quartz sand, and lavender shale. The lower boundary of this formation has been arbitrarily selected at 5,760 feet in the Connaghan well No. 5 since apparently there is no definite lithologic or electric-log break at its base. The Gallatin thus attains a thickness of 515 feet.

Gros Ventre formation.—Consisting essentially of dark, grayish green platy shale with paper-thin interbeds of gray micaceous and glauconitic sandstone, this formation attains a thickness of 485 feet according to the writer's interpretation of the Connaghan No. 5 sample and electric log (Fig. 4). In a glauconitic sandstone near its base, some light oil staining was found. The lower boundary of this marine deposit is placed at the top of a very fine-grained, light buff, slightly oil-stained sandstone thought to be a part of the light gray, coarse-grained Flathead sandstone below.

Flathead sandstone.—This sandstone lies on the eroded, weathered surface of the Archean granitic rocks. The basal 15 feet contain coarse angular fragments of pink feldspar and quartz that were obviously derived from the underlying

[16] G. Duncan Johnson, "Geology of the Mountain Uplift Transected by the Shoshone Canyon, Wyoming," *Jour. Geology*, Vol. 42, No. 8 (1934), pp. 817–18.

[17] T. F. Stipp, "Paleozoic Formations near Cody, Park County, Wyoming," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31, No. 2 (February, 1947), pp. 277–78.

[18] *Ibid.*, p. 278.

pegmatite dikes which are predominantly composed of pink orthoclase and quartz. The upper part of the Flathead, however, is composed of coarse, angular, vitreous quartz fragments set in a finer-grained matrix consisting of better sorted, much finer-grained quartz sand. This sandstone showed great porosity and permeability when it was tested for the light oil saturation present. Unfortunately it made only large quantities of fresh water. This sandstone has a thickness of 128 feet in the Connaghan well No. 5.

STRUCTURE

Surface.—The geomorphic form of the Mesaverde outcrops at Oregon Basin fully illustrate the configuration and size of the surface anticline (Fig. 3). Inliers of the Frontier sandstone, located as they are in the topographic depression occupied by the Cody shale, further exemplify the structural "high." Displacements of the Mesaverde rim rock and of the Frontier outcrops on the crest of the north dome show the location of the surface trace of most of the faults which are known to cut the Embar-Tensleep zone. All faults appear to be high-angle tensional and shear fractures which occurred contemporaneously with the folding of the Oregon Basin anticline. Lateral relief of the compressive stresses resulting in the anticlinal uplift is here advanced as the cause of the faulting. It is significant that these faults die out on the flanks of the structure.

The upthrown fault segment on the south end of Oregon Basin is shown unmistakably by the offsets in the Mesaverde outcrops on either flank.

Subsurface.—Adequate well data are available to delineate an accurate structure map on the top of the Embar limestone (Fig. 6). A subsurface west-east cross section on the south dome (Fig. 7) shows the general assymetrical nature of the fold. The steeper side is on the west, away from the basin, which is characteristic of the Big Horn basin type of folding.

Oregon Basin is unique in its having two, separate domes on a north-trending axis, especially as most Big Horn basin folds trend northwest rather than north and none has separate closures of this magnitude on the same axis. Although the Embar limestone in the upthrown fault block on the south end of Oregon Basin, shown on both the mosaic and the structure maps (Figs. 3 and 6), is below the Embar water line in the main part of the field, it is nevertheless productive because of the fault trap. The Embar in the upthrown fault block is sealed off against the impermeable upper Dinwoody and lower Chugwater shales, whereas the porous Tensleep sandstone in the fault block is opposite the water-bearing Embar and is consequently itself water-bearing.

Age of folding and faulting.—If appreciable structural growth had occurred during deposition of the late Paleozoic and Mesozoic strata, the structural cross section (Fig. 7) should show recognizable anomalous changes in the thickness of those beds. Since no variation can be detected it is assumed that folding began at Oregon Basin during late Upper Cretaceous time, probably immediately fol-

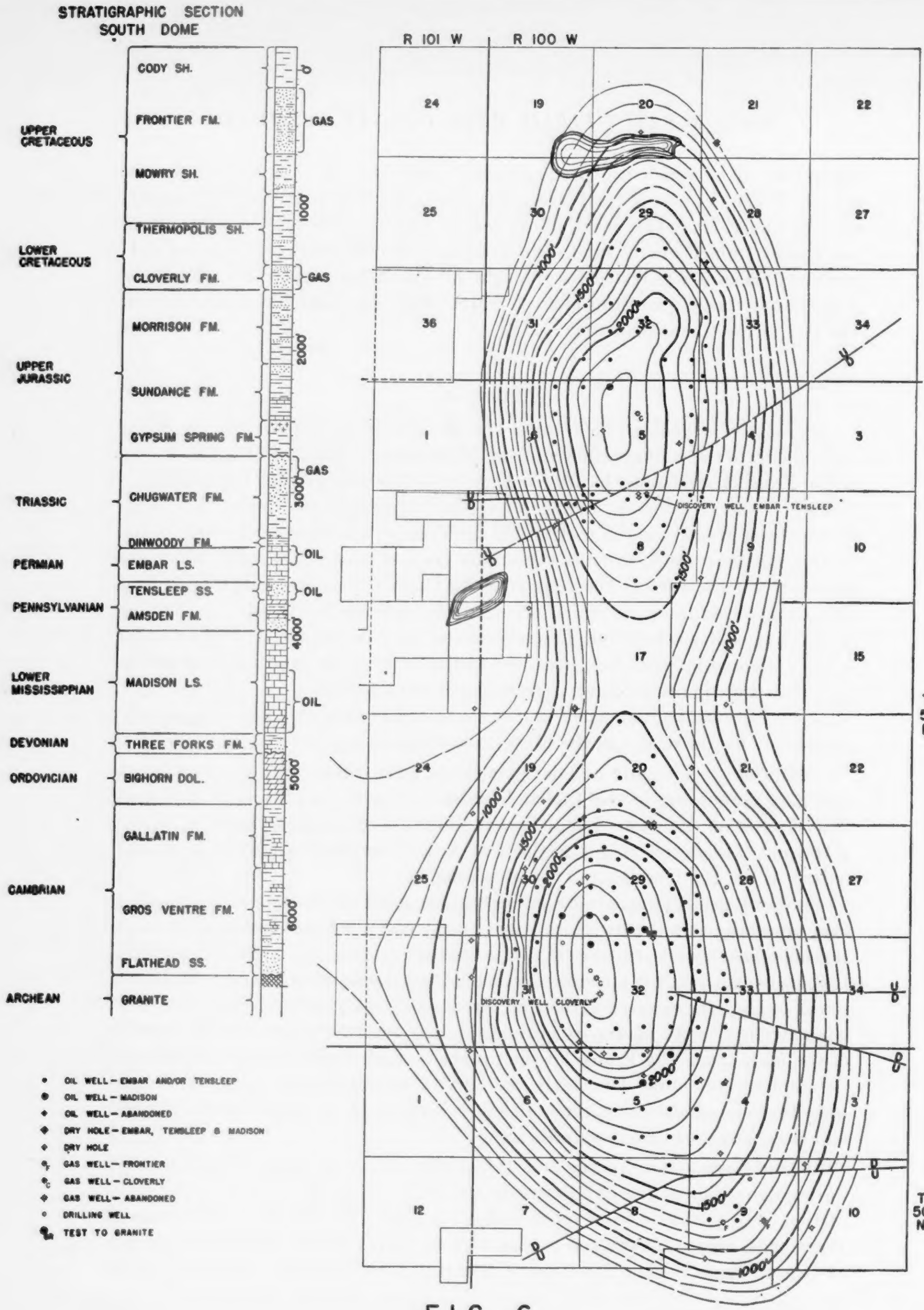

FIG. 6

STRUCTURE MAP OF OREGON BASIN, WYOMING

CONTOURS ON EMBAR LIMESTONE

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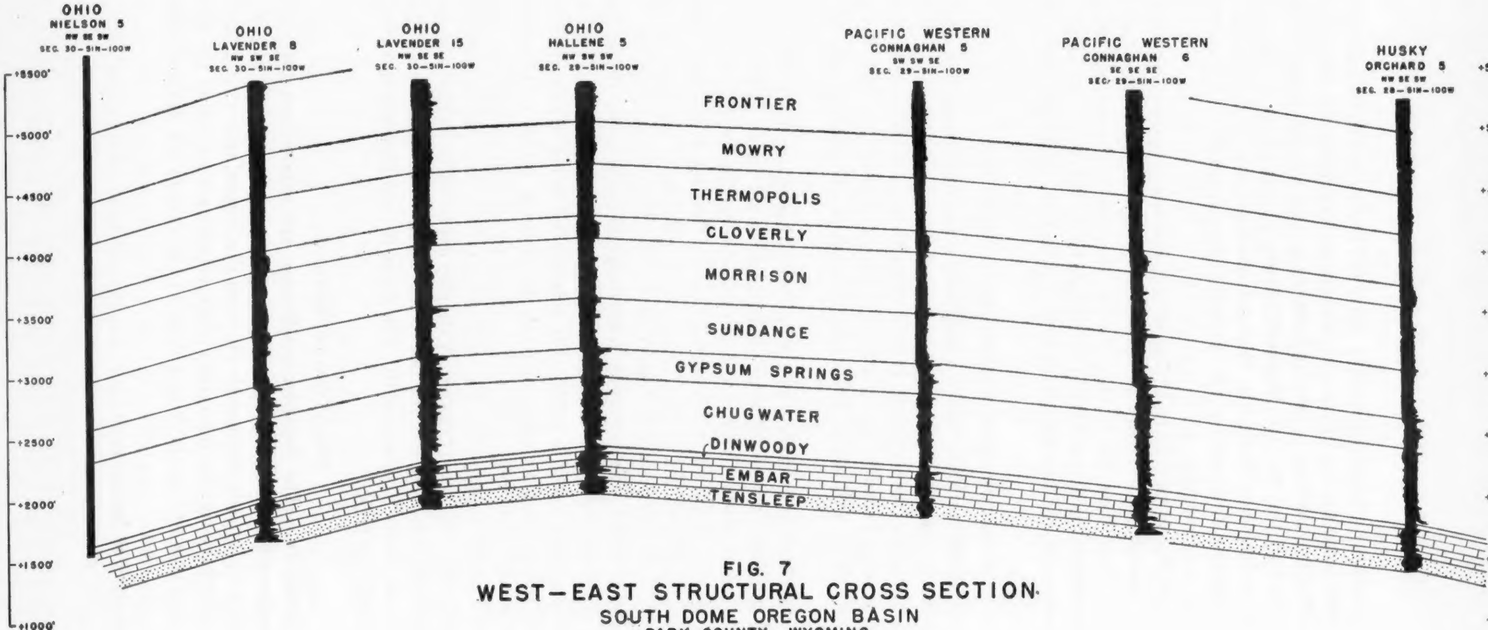

FIG. 7
WEST—EAST STRUCTURAL CROSS SECTION
SOUTH DOME OREGON BASIN
PARK COUNTY, WYOMING
HORIZONTAL SCALE SAME AS VERTICAL
PAUL T. WALTON
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lowing deposition of the Lance formation. Hewett[19] has shown that the Paleocene Fort Union strata overlap the Lance and Meeteetse formations on the east flank of the fold, indicating the first appreciable movement at Oregon Basin to be pre-Fort Union. Though the Eocene Wasatch strata overlap Fort Union, Lance, and Meeteetse on the east flank, the Wasatch beds show definite indication of having been folded at both ends of the anticline; thus, post-Wasatch movement unquestionably occurred (Fig. 3).

Some of the faulting cuts Fort Union strata, but none apparently cuts Wasatch. This is convincing evidence for placing the age of the faulting as post-Fort Union and pre-Wasatch. If this is true, then only the earlier Paleocene folding was accompanied by faulting. Judged by the deformation of the Wasatch beds, the Eocene folding was less intense and possibly consisted principally of uplift.

RELATION OF STRUCTURE TO ACCUMULATION

The Oregon Basin anticline has a maximum structural closure in excess of 1,600 feet, including the north and south domes which have independent closures of 700 feet and 900 feet, respectively. It is obvious that an anticline of this structural magnitude would readily act as a trap for migrating oil and gas. Anticlinal structure, therefore, is primarily the primary cause of the oil and gas accumulation.

Faulting is of little importance as a trap, excepting in the fault block in the south end of the field, where oil accumulation is found in an upthrown block along the axis. Local productivity of the various producing formations is largely controlled by stratigraphic variation which induces changes in porosity and permeability. Lateral gradations of the Tensleep into dolomite account for higher Tensleep productivity on the north dome than in the south dome, but this change is not construed as being of importance in the original trapping of the oil pool.

Flushing of oil pools by moving ground waters is frequently given as the reason for finding fresh water in potentially productive zones on closed anticlines instead of oil. While large volumes of fresh water were found in the Flathead sandstone, this could not very well be construed to be due to flushing, else the shallower zones ought to contain fresh water also. Selective flushing by ground waters certainly does not seem tenable. A simpler explanation is that the body of water in which the Flathead and the immediate overlying strata were deposited was fresh and not saline; consequently, the connate and formation waters now contained therein are fresh.

PRODUCING FORMATIONS

Frontier formation.—The Frontier sandstones are exposed on the crests of both north and south domes. However, in the upthrown fault block at the south end of the field a well produces enough gas from this formation to run a lease and operate a small rotary rig. No reservoir characteristics are known of the Frontier sand except that this well initially produced at the rate of 7.6 million cubic feet per day.

[19] D. F. Hewett, *op. cit.*, pp. 35–37.

Cloverly formation.—One well on the north dome produces commercial amounts of gas from the Cloverly sandstone. It is connected with the Rocky Mountain Gas Company line and furnishes the town of Cody with gas. Its production approximates 7 million cubic feet per day.

Nothing is known of the reservoir characteristics of the Cloverly sandstone, excepting that this well produced initially an estimated 25 million cubic feet of gas per day and had a shut-in casing-head pressure of 680 pounds at that time. Inasmuch as this well was completed in 1916 and has been producing almost constantly ever since, the Cloverly sandstone must be considered as a very good gas reservoir.

A Cloverly sandstone well on the south dome which produced initially 20 million cubic feet of gas per day is presently shut in. No further data are known about this well.

Morrison formation.—The two gas wells in this formation were short-lived and so have been abandoned. No further data are available, excepting that the gas came from thin, tight sands and was soon exhausted.

Chugwater formation.—The two wells which produced gas from this formation on the north dome have been drilled to the Embar limestone, from which they are now producing oil. One of these wells has produced from a bradenhead for lease use only.

Little is known of reservoir characteristics of the Chugwater sands except that one well produced initially one million cubic feet of gas per day, and the other produced initially at the rate of 1.6 million cubic feet.

Embar limestone.—On December 1, 1946, there were 136 producing oil wells on the north and south domes in this formation. Some of these were dual completions with the Tensleep. One well in the SE. $\frac{1}{4}$, SE. $\frac{1}{4}$ of Sec. 6, north dome, which produced 6 million cubic feet of gas per day initially from the Embar has been recompleted as a Tensleep well. One well in the SW. $\frac{1}{4}$, SW. $\frac{1}{4}$ of Sec. 28, north dome, which formerly produced oil now makes water only and has been abandoned.

Few basic data are known about this oil- and gas-producing formation. No extensive bottom-hole pressure surveys or gas-oil ratio measurements have been made. Some gas is made with the oil, although nearly all of the wells are now pumped. At some wells the amount of gas is sufficient to operate a lease. Most wells, if they produce very long, make considerable water, no matter what their structural location is. Probably this water represents both edge-water encroachment and bottom-hole water coming into the wells from vertical fractures. Data obtained from low-flank wells indicate edge water to have an approximate structural elevation of +1450 feet on both domes. In addition, there are local areas where a fracture system is unquestionably present, for some wells are strongly affected by the withdrawal from others. These fractures probably account for much water in areas where they extend downward below the Embar water table.

Although the data available for this paper are insufficient to prove that on the crests of the twc domes the Embar is relatively non-porous and impermeable and thus capable only of producing small amounts of oil and gas, the tendency

toward this condition has been inferred from the behavior of several wells. On flank locations the Embar has shown excellent porosity and permeability with initial productivity as high as 2,800 barrels per day, particularly after acidization.

The upper 30–50 feet of the Embar probably accounts for most of the production. While good saturation is everywhere found in lower zones in the limestone, little or no fluid, either oil or water, can be extracted from this zone in wells above the water table. Drill-stem tests in this zone indicate absence of formation pressure.

Tensleep sandstone.—On December 1, 1946, there were 6 wells on the south dome and 4 wells on the north dome producing solely from the Tensleep sandstone. As with the Embar, basic data on the Tensleep as to its reservoir characteristics are lacking. If the few producing wells can serve as a criterion for the Tensleep in the field as a whole, it may be said that the Tensleep produces little gas and water with the oil.

As already described the Tensleep sandstone has a thickness varying from 20 to 180 feet and may change in a short distance laterally or vertically into dense barren dolomite. Its relatively low porosity and permeability induced by dolomitic cementation and compression mark it as a slower and steadier producer than the Embar. Unlike the Embar which may show a sharp decline in production, Tensleep production is characterized by a flat decline curve. Initially, production from the Tensleep seldom exceeds 200 barrels, particularly on the south dome where a thinner section is present.

The Tensleep area of production on both domes, as far as can be determined, is identical in size and location with that of the Embar. The inference that the two reservoirs were at one time interconnected by faulting or fracturing is further strengthened by the close agreement of the gravities of the oil from the two zones. The two gravities differ no more than 0.3°, which is a smaller variation than is commonly found in the same producing formation in other fields.

Madison limestone.—On December 1, 1946, one well on the north dome and four on the south were producing from this formation. Several wells on both domes that were drilled to the productive zones of the Madison have been plugged back and completed in the Embar. Six wells on the north dome and probably one well on the south found only water in the Madison.

No basic data are available for this paper, and wells in this zone have not been producing a sufficient time to allow any generalizations to be made of the reservoir characteristics. Though initial production as high as 400 barrels per day has been reported, it is not known how this production will decline.

Oil saturation occurs intermittently in two general zones, one extending from 260 to 450 feet from the top, and the other from 570 to 640 feet from the top. The oil occurs in vugs and in pore spaces between the individual calcite crystals. Some dolomitization is the cause of the porosity in the lower zone.

The bottom-hole water table is fairly well located at a datum near +1500 feet in the north dome and +1400 feet in the south dome. Since the water table

in the Embar is at a +1450 datum this must be considered as further evidence for intercommunication between the Embar, Tensleep, and Madison formations even though the gravity of the Madison oil may be a maximum of 4.2° lower than that of the Embar. Significantly, Madison oil gravities from different wells vary as much as 0.8°.

PRODUCTION

Drilling methods.—The Cloverly gas wells were drilled with cable tools. The Embar-Tensleep discovery well was drilled with rotary to the top of the Embar

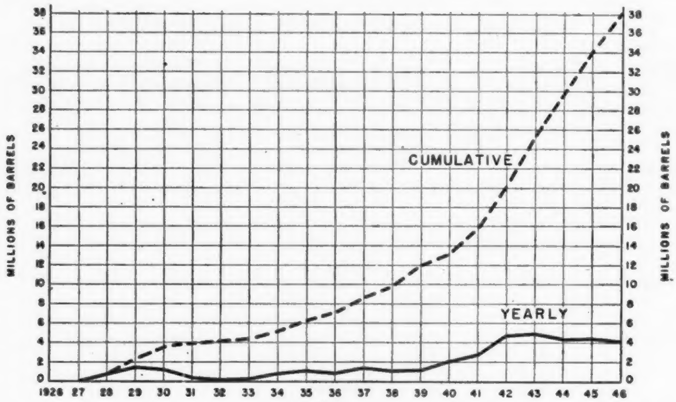

FIG. 8
PRODUCTION CURVES
OREGON BASIN FIELD
PARK COUNTY, WYOMING
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and cable tools were used to drill into the oil-bearing formations. All subsequent drilling to the oil formations has been with rotary equipment and it is no longer the practice to drill in with cable tools.

Completion practice.—The present practice for completing the Embar wells is to drill to the base of the Tensleep sand and then set either 7-inch or $5\frac{1}{2}$-inch casing near the bottom of the hole. The casing is then perforated opposite the pay zones in the Embar, tubing and rods run, and the mud displaced with oil. When the Embar is depleted it is planned to squeeze it off and perforate opposite the Tensleep. A variation of this procedure is to drill to the base of the Tensleep sand and set the casing at its top with a Baker "Triplex" or Larkin "Cementrol" cementing shoe. The plug in the shoe is left undrilled and the casing is perforated opposite the Embar. The advantage of this method is that it keeps the cement away from the Tensleep and allows the sand to be shot with nitroglycerine if necessary.

Since 1935 most Embar wells have been acidized as they were completed. Usually only 500 gallons are necessary to clean the mud from the formation and initiate production.

The Madison wells are commonly drilled to the top of the Devonian where $5\frac{1}{2}$-inch or 7-inch pipe is set. Selective perforation is started at the bottom of the hole and the mud is swabbed out through tubing. If the oil coming into the hole has too great a water cut, the perforations are squeezed and a higher zone is perforated. Several up-hole stages of selective perforating and squeezing may be necessary to complete the well.

Crude-oil characteristics.—The following tables prepared from data by Crawford and Larsen[20] list the important characteristics of the oil produced at Oregon Basin.

CHARACTERISTICS OF OIL PRODUCED AT OREGON BASIN

Gravity API°	*Sulphur Percentage*	*S.U.V. (100° F. Secs.)*	*Carbon Residue %*	*Total Gasoline %*	*Base of Crude*
			EMBAR		
North Dome 22.8	2.91	177	7.4	15.3	Intermediate naphthene
South Dome 20.7	3.20	326	9.1	14.0	"
			TENSLEEP		
North Dome 23.1	2.77	154	6.1	14.2	"
South Dome 20.5	3.33	348	7.9	13.5	"
			MADISON		
South Dome 16.5 to 17.3	3.49 to 3.68	996 to 1320	7.1 to 9.1	8.5 to 8.7	"

Production curves.—The total cumulative and annual production of all producing zones of the Oregon Basin field is shown in Figure 8. At the end of 1946 the total production of the field amounted to 38,293,658 barrels.[21] The flush production during the 2 years following the discovery was due to testing and competitive drilling. The lack of market and the depressed price during the depression years of the early 30's are clearly evident on the yearly curve. The yearly curve also shows that accelerated war-time demands caused the rise in production during the early 40's, and that a tapering-off of production during 1944–1946 was necessary to meet the smaller domestic demands.

Pipe lines and outlets.—The Rocky Mountain Gas Company's line from the north dome into the town of Cody serves as the outlet for the gas produced for other than lease use. The Ohio Oil Company's pipe line to its loading racks on the Burlington Railroad near Cody serves as the tank car outlet. The connection of the Ohio line on the east side of the field with the Stanolind Oil and Gas Company's Elk Basin-to-Casper line, which is a common carrier, provides an outlet to the three refineries at Casper.

[20] J. G. Crawford and R. M. Larsen, "Occurrences and Types of Crude Oils in Rocky Mountain Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 10 (October, 1943), pp. 1305–34.

[21] Data from United States Geological Survey, Casper, Wyoming.

Future development.—The Connaghan well No. 5, near the crest of the south dome, has tested all potentially productive formations from the surface to the Archean granite. No new producing formations were found. Insofar as the development of new oil zones are concerned, Oregon Basin seems to have little left in store for its future. Detailed geologic studies indicate no possibility of overlaps or truncations around its flanks which might be productive. Oregon Basin's future appears to be confined to the development of its presently known oil-producing formations, the Embar, Tensleep, and Madison.

Approximately seventeen 40-acre pattern locations on the south dome and sixteen on the north dome are proved for the drilling of combination Embar-Tensleep wells. Proved, undrilled 40-acre locations for Madison wells number nineteen on the north dome and thirty-one on the south. Seventy-three wells to be drilled in routine field development can easily be envisioned. Their drilling would encompass a sizable expenditure of capital, and a considerably increased production from Oregon Basin would no doubt result.

For the still distant future a large secondary-recovery program of some kind for the Tensleep sand can be reasonably safely predicted. This sand should lend itself well to such production practice, should the economics of that distant day (estimated 25 years hence) be such as to make it profitable.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 8 (AUGUST, 1947), PP. 1454-1471, 4 FIGS.

UPPER MONTANA GROUP, GOLDEN AREA, JEFFERSON COUNTY, COLORADO[1]

JOHN D. MOODY[2]
Golden, Colorado

ABSTRACT

Detailed examination of the upper part of the Montana group in the vicinity of Golden and Morrison, Jefferson County, Colorado, has revealed the presence of a series of beds more than 1,200 feet thick containing a well developed and varied Fox Hills fauna. These beds have been divided, on the basis of lithology and fauna, into four zones which are continuous and mappable for at least 20 miles along the outcrop. The base of the Fox Hills sandstone as restricted by the United States Geological Survey lies more than 1,000 feet above the first appearance of a typical Fox Hills fauna in the section.

The basal members of the overlying Laramie formation rest on different zones of the upper Montana at different localities within the area. This has been interpreted as indicating a disconformity between the two, at least in the Golden area. Evidence is cited to substantiate this interpretation.

The Montana shales below the restricted Fox Hills are readily divisible into upper, middle, and lower Pierre, as has been established in northeastern Colorado. The middle Pierre, including several prominent sands, is particularly well developed in this area.

Structural and historical implications of the interpretation are discussed.

INTRODUCTION

OBJECT

During the course of a field investigation of the Laramie formation in the Golden area evidence was found which suggested an unconformity between the Laramie and the underlying Montana group. This, together with several statements in published reports, prompted the writer to undertake a zonation of the Montana group in order to discover further evidence. This paper is a discussion of the stratigraphy and paleontology of the Montana group, with emphasis on the upper part.

GENERAL

The Golden area is in the foothills belt of the Front Range in the central part of Jefferson County, Colorado, 13 miles west of Denver (Fig. 1). The structure is dominated by the foothills monocline, representing the east limb of the great Front Range anticline. The truncated edges of beds ranging in age from pre-Cambrian to Paleocene are exposed in a series of hogbacks, mesas, and buttes which make up the foothills of the Front Range. These sedimentary rocks are broken by a series of great faults, the full nature and exact location of which are not known. At some localities, however, as much as 7,000 feet of strata are missing.

The Upper Cretaceous series is well represented, consisting, in ascending order, of the Dakota formation; the Benton and Niobrara formations which comprise the Colorado group; the Montana group; and the Laramie formation.

[1] Manuscript received, April 18, 1947.

[2] Colorado School of Mines. The writer wishes to thank J. Harlan Johnson for his aid, interest, and encouragement; Mrs. J. D. Moody for assistance rendered in all phases of the work; and J. B. Reeside, Jr., for identifying some of the fossils.

The outcrop of the Montana strata is in a broad valley between hogbacks developed on more resistant beds. Figure 2 shows the location of the Montana outcrop within the area.

The monumental work of Emmons, Cross, and Eldridge[3] is outstanding among several early contributions to the geology of the foothills region. This report gave a complete description of the geology of the Denver basin, and has served as the basis for subsequent stratigraphic studies. The next publication covering the stratigraphy of the area appeared in 1934, and contained only general information.[4] R. W. Brown,[5] in 1943, published an excellent article on the Cretaceous-

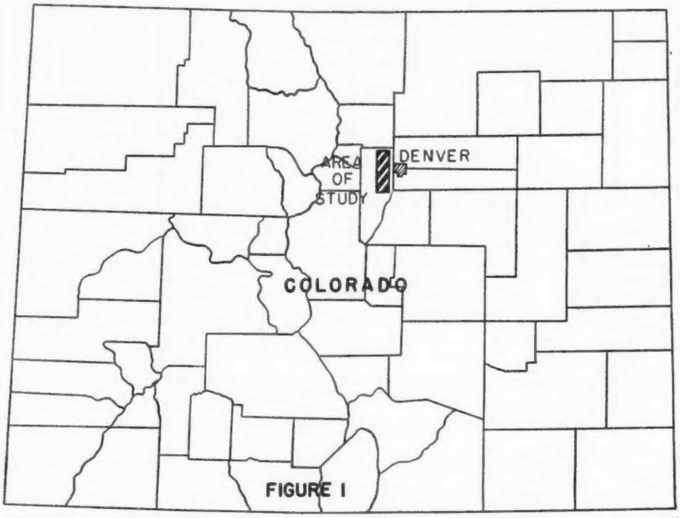

FIG. 1.—Map of Colorado showing location of Golden area. Area discussed is 6.75 miles wide and 17.50 miles long.

Eocene contact in the Denver basin, in which he proposed a new definition of the term Laramie. However, his discussion did not include strata as old as Montana. The stratigraphic studies of LeRoy[6] in 1946 represented a real step forward in understanding the sedimentary sequence in the district, but his statement con-

[3] S. F. Emmons, C. W. Cross, and G. H. Eldridge, "Geology of the Denver Basin," *U. S. Geol. Survey Mon. 27* (1896).

[4] J. H. Johnson, "The Geology of the Golden Area, Colorado," *Colorado School Mines Quar.*, Vol. 25, No. 3 (1930).

[5] R. W. Brown, "Cretaceous-Tertiary Boundary in the Denver Basin, Colorado," *Bull. Geol. Soc. America*, Vol. 54 (1943), pp. 65–86.

[6] L. W. LeRoy, "Stratigraphy of the Golden-Morrison Area, Jefferson County, Colorado," *Colorado School Mines Quar.*, Vol. 41, No. 2 (1946).

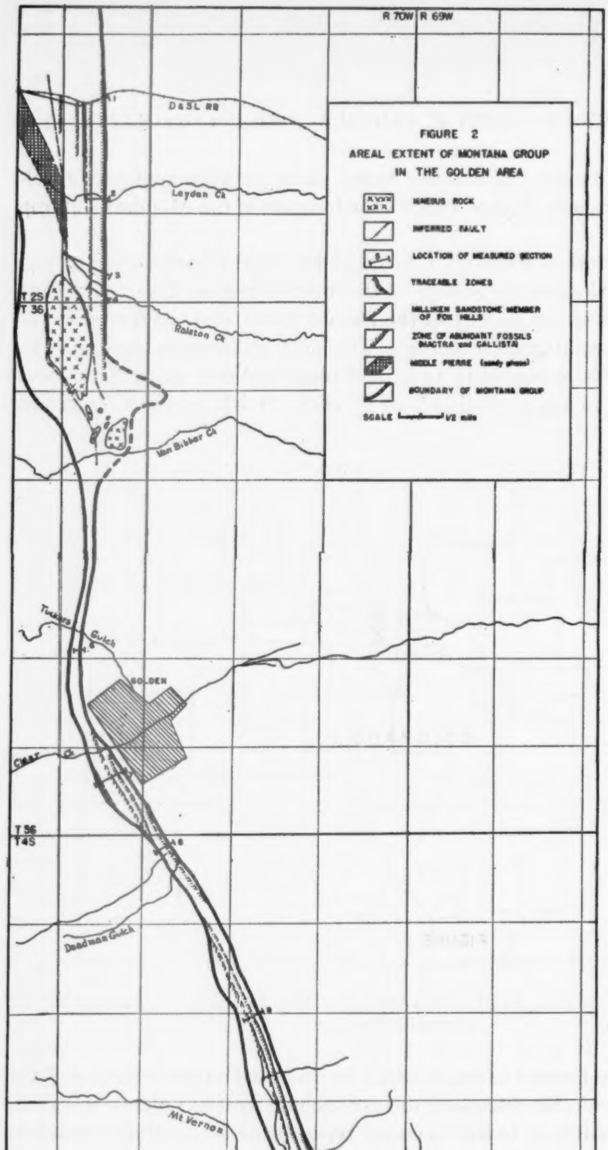

FIG. 2.—Map showing areal extent of Montana group in Golden area. Traced from Golden and Morrison quadrangles.

cerning the Montana group did not contain much detailed information.

Definitions of stratigraphic units as used in the present discussion are as follows.

Laramie is used in the sense of R. W. Brown,[7] and includes all strata between the Cretaceous-Paleocene contact and the marine beds of the Montana group.

Montana is used in its original sense and includes all the strata between the Laramie formation and the Apishapa shale of the Niobrara formation.

Fox Hills as a formation name is used in the restricted sense as defined by Lovering *et al.*[8]

> The base of the Fox Hills shall be considered as the horizon below which the section is predominantly gray marine clay shales and sandy shales of Pierre age, and above which the section changes rapidly to a buff to brown sandstone containing numerous large gray to brown, hard, sandy concretions. This lower concretionary member is commonly overlain by a series of light gray to brown sandstones and sandy shales.
>
> The top of the Fox Hills formation shall be considered as the horizon above which the section is composed predominantly of fresh- and brackish-water deposits accompanied by coals and lignitic shales, and below which it is predominantly marine.

The term "Fox Hills fauna," however, is meant to describe the suite of fossils occurring in the Fox Hills as originally set up by the Hayden Survey.[9]

Milliken is used to indicate the basal sandstone member of the Fox Hills formation as restricted in the preceding paragraphs.

Pierre is used to include all the beds below the restricted Fox Hills and above the Niobrara formation.

STRATIGRAPHY

CONTROL SECTIONS

Figure 2 shows that along much of the outcrop the Montana strata are abnormally thin. This loss of section between Bear Creek and Leyden Gulch is the result of a complicated system of faulting which affects at least all the Cretaceous and older formations. For this reason detailed control sections were measured along the Denver and Salt Lake City Railroad on the north, and in Bear Creek Valley on the south, where the Montana section is relatively complete.

Following is a composite section measured along the right-of-way of the Denver and Salt Lake City Railroad, north of Golden.

	Thickness (Feet)
Massive buff medium-grained quartz sand with black tourmaline	47
Laminated gray clay parting	2
Massive buff medium-grained quartz sand with black tourmaline	4

[7] R. W. Brown, *op. cit.*, pp. 84.

[8] T. S. Lovering, H. A. Aurand, C. S. Lavington and J. H. Wilson, "Fox Hills Formation, Northeastern Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 7 (1932).

[9] F. B. Meek, "A Report on the Invertebrate Cretaceous and Tertiary Fossils of the Upper Missouri Country," *U. S. Geol. Survey of the Territories* (1876).

	Thickness (Feet)
Laramie-Montana contact	
Fine-grained buff laminated ripple-marked quartz sand with abundant biotite and muscovite, trace glauconite	9
Laminated fine-grained sand and sandy shale, with small ferruginous concretions	18
Fine-grained buff very lignitic micaceous sand	6
Interbedded gray to buff very lignitic fossiliferous sand and sandy shale, with *Pteria nebrascana, Yoldia evansi, Nucula cancellata, Lunatia* sp. aff. *occidentalis*	24
Laminated hard gray to drab fossiliferous sandy shale with ferruginous cone-in-cone concretions, *Lucina subundata, Yoldia evansi, Lunatia* sp.	234
Interbedded sand and sandy shale with abundant plant remains and fossil fragments	18
Laminated buff to drab sandy shale and shale	356
Buff fine-grained laminated sand	2
Interbedded laminated sand and sandy shale	25
Laminated fine-grained buff sand with few shaly streaks	18
Laminated fine-grained buff sand and sandy shale	16
Laminated sandy shale with thin ironstone streaks	217
Thinly laminated fine- to medium-grained greenish buff glauconitic ashy sand with *Discoscaphites nicolleti, Baculites* sp., *Inoceramus* sp. aff. *barabini, Nucula cancellata, Yoldia evansi, Callista* sp., *Mactra* sp., *Fusus dakotensis, Lunatia* sp. aff. *subcrassa*	42
Laminated drab to gray-buff sparingly fossiliferous shale and sandy shale with ferruginous cone-in-cone concretions	84
Drab blocky very sandy shale	26
Laminated gray to drab sandy shale and shale	188
Buff to drab very sandy fossiliferous shale with *Baculites* sp., *Callista* sp., *Geltena (Mactra) gracilis*	15
Covered	835
Laminated buff sandy shale	95
Laminated medium-grained buff silty sand	2
Blocky to laminated buff sandy shale with fossiliferous ironstone concretionary bands with *Acanthoscaphites nodosus* var. *plenus, Inoceramus barabini*	36
Laminated drab sandy shale with thin sand streaks	59
Blocky drab sandy shale	26
Buff-gray fossiliferous shaly sand with *Acanthoscaphites* sp., *Inoceramus barabini, Callista* sp.	27
Blocky drab to buff silty sand	8
Laminated sandy shale with thin sand streaks	24
Buff blocky shaly sand	8
Laminated to blocky drab sandy shale	120
Buff laminated shaly sand	6
Laminated drab sandy shale	180
Covered	1200
(A major fault cuts section in this vicinity; hence, detailed section was not carried farther)	
Buff to drab laminated shale and sandy shale	800
Buff to gray laminated shale and sandy shale with some laminated fossiliferous glauconitic sand with *Acanthoscaphites* sp., *Baculites* sp. aff. *compressus, Inoceramus barabini, Inoceramus* sp. Shales and sandy shales of above section are very lignitic, with much comminuted plant material	1500
Very dark gray thinly laminated tough fissile shale with small calcareous concretions, thin bentonite seams, fish scales, *Baculites* sp. aff. *asper*	420
Montana-Niobrara contact	
Buff to gray very calcareous speckled shale 15	
Maximum observed thickness of Montana	6644

The following section is a composite of several sections measured in Bear Creek valley, 8 miles south of Golden.

		Thickness (Feet)
Massive white medium- to coarse-grained clean quartz sand with black tourmaline	69	
Laramie-Montana contact		
Gray to dark gray very lignitic sandy shale		20
Laminated buff to drab fossiliferous shale, with *Nucula cancellata, Yoldia evansi*, fish scales		63
Buff laminated ripple-marked medium- to fine-grained micaceous sandstone with large ferruginous concretions and fossil fragments, abundant plant remains, leaves, *et cetera. Baculites* sp., *Pteria nebrascana*		48
Drab to gray laminated clay shale and sandy shale with ironstone bands, cone-in-cone concretions, *Discoscaphites nicolleti, Baculites compressus, Lucina subundata, Pteria linguiformis, Pteria (Pseudoptera) fibrosa*		848
Greenish buff glauconitic laminated fossiliferous sand with *Discoscaphites* sp., *Baculites compressus, Callista* sp., *Geltena (Mactra) gracilis*		53
Drab laminated shale and sandy shale with *Discoscaphites nicolleti, Baculites* sp., *Nucula cancellata, Yoldia evansi, Callista* sp., *Geltena (Mactra) gracilis*		160
Gray to drab laminated shale and sandy shale with thin streaks of bentonite		4000
Greenish buff to gray glauconitic fossiliferous sand and sandy shale with *Baculites compressus, Inoceramus barabini, Inoceramus* sp.		1500
Dark gray tough fissile shale with fish scales		500
Montana-Niobrara contact		
Buff calcareous speckled shale	135	
Maximum observed Montana thickness		7192

ZONATION

Data from the foregoing sections located at the extremities of the area make it possible to divide the Montana into four main parts, and to establish a detailed zonation of the upper part of the group. Figure 3 is a composite section for the whole area, and presents graphically the zonation here described.

The basal unit of the Laramie formation is ordinarily massive white to buff medium- to coarse-grained quartz sand. Following is a detailed lithologic description of this unit at Leyden Gulch (section 2, Fig. 2).

> Massive white medium- to coarse-grained clear quartz sand, with few smoky quartz grains; black tourmaline common; sand is well cemented with white non-calcareous cementing material but is very friable; grains show considerable variations in sphericity and somewhat less variation in roundness; many rolled secondary quartz crystals; slight limonite stain throughout.

This description is fairly typical of all the lower Laramie sands in the vicinity of Golden. However, some samples show considerable limonite staining, calcareous cementation, and development of small ferruginous concretions. The sands of the upper part of the Montana are ordinarily quite distinct from the Laramie sands, in that they are finer-grained, contain much biotite, muscovite, and glauconite, and present a generally trashy appearance.

The contact of the Laramie with the underlying Montana beds is ordinarily sharp and distinct, and the basal sand commonly contains clay pebbles apparently derived from the beds below. Emmons, Cross, and Eldridge[10] have this to

[10] S. F. Emmons, C. W. Cross, and G. H. Eldridge, *op. cit.*, p. 89.

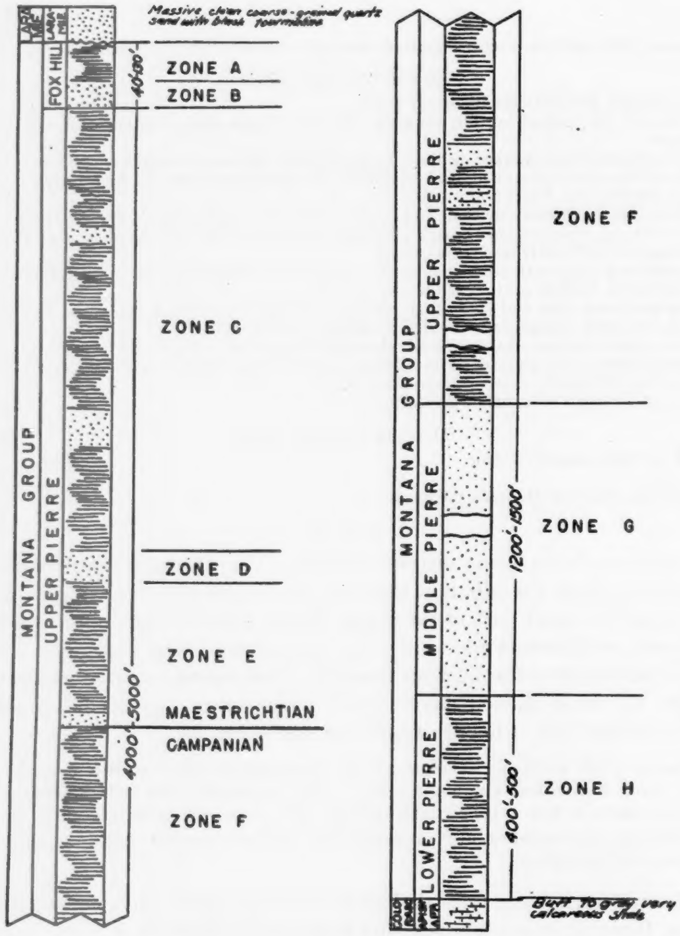

FIG. 3.—Composite section of Montana group showing stratigraphic zones. Thickness indicated in feet.

say about the relation between the basal Laramie sand and the first sand in the Montana, in the Golden area.

. . . The sandstone at the summit of the formation (Fox Hills) is noteworthy on account of its position as cap to the great mass of Cretaceous clays, from its wide occurrence over the west, from the fossil remains in its upper stratum, and from the marked difference displayed in its materials from those of the basal sandstone of the Laramie which overlies it. Its composition is chiefly quartz, but it contains an appreciable amount of biotite and

muscovite, and iron oxide is distributed throughout its mass. It is fine-grained, of close texture, and usually occurs as a single bed. Occasionally it becomes concretionary. It is in close union with the basal sand of the Laramie; no transition bed exists; the passage from the one to the other is distinct; combined they frequently enter into the formation of a single bluff one hundred and fifty feet high. . . .

This description corresponds with Zone B of this paper. North of Van Bibber Creek the basal Laramie sand rests on this bed; however, on the south there is a shale sequence which intervenes between the two, which is here designated as Zone A of the Montana group.

Zone A is the uppermost member of the Montana group in the Golden area, and varies in thickness from 83 feet in Bear Creek valley to nothing north of Golden. Where present, it is commonly divisible into two parts—an upper shale which is dark gray, very lignitic and sandy, with abundant comminuted plant fragments, and a lower clay shale which is much less lignitic and contains the following fauna.

Discoscaphites nicolleti (Morton) Meek
Lucina subundata Meek & Hayden
Nucula cancellata Meek & Hayden
Tellina sp.
Yoldia evansi Meek & Hayden
Dentalum sp.
Lunatia occidentalis Meek & Hayden
Cylichna volvaria Meek & Hayden
Fish scales

According to LeRoy[11] the entire shale section contains the arenaceous foraminifer *Haplophragmoides*. The maximum observed thickness of the zone is 88 feet. The common occurrence of a large form of *Nucula cancellata* is diagnostic. The shells have a peculiar and very distinctive preservation—both valves are present and together, and the shell is surrounded with a "keel" of secondary calcite.

The fossiliferous shales of Zone A are transitional into fine-grained buff ripple-marked sandstone, which is here designated Zone B. This is apparently the sandstone referred to in the passage from Emmons, Cross, and Eldridge previously cited. Its thickness in the area varies from 48 feet to nothing. The sandstone is well laminated, with thin breaks of shale and sandy shale here and there. It commonly contains an abundance of plant material, and south of Green Mountain the following fauna.

Baculites sp. aff. *asper* Morton
Pteria nebrascana Evans & Shumard
Shell fragments

In most exposures large brown ellipsoidal concretions are a prominent feature of this unit. Following is a detailed lithologic description of the sand from section 10 (Fig. 2).

Buff fine-grained well-laminated quartz sand with ripple-marks; biotite and muscovite abundant, glauconite rare, varicolored quartz grains frequent; many small brown specks

[11] L. W. LeRoy, *op. cit.*, p. 86.

which in some instances are pseudomorphs of limonite after pyrite; limonitic throughout; much comminuted plant material; shell fragments in upper stratum.

Underlying the concretionary sandstone of Zone B is a thick sequence of drab to gray well laminated shale and sandy shale which attains a thickness of 920 feet at section 1 (Fig. 2). Ironstone concretionary layers which in places exhibit cone-in-cone structure are common. In the lower third a well defined zone of laminated sand and sandy shale is traceable for several miles. This entire shale unit has been designated Zone C. The shales are commonly very lignitic. The following fossils have been identified.

Sphenodiscus lenticularis Owen
Discoscaphites sp. aff. *nicolleti* (Morton) Meek
Baculites compressus Say
Pteria nebrascana Evans & Shumard
Pteria linguiformis Evans & Shumard
Pteria (*Pseudoptera*) *fibrosa* Meek & Hayden
Leptosolen sp.
Lucina subundata Meek & Hayden
Nucula cancellata Meek & Hayden
Nuculana sp.
Jellina sp.
Yoldia evansi Meek & Hayden
Dentalium sp.
Lunatia occidentalis Meek & Hayden

LeRoy[12] has noted the occurrence of *Haplophragmoides* in the upper 130 feet of this section.

Below the shales of Zone C is greenish gray glauconitic well laminated very fossiliferous sandstone. This unit maintains a nearly constant thickness of approximately 50 feet throughout the area, and lithologically is very similar to the sandstone of Zone B. The following fossils have been identified.

Discoscaphites conradi (Morton) Meek
Discoscaphites nicolleti (Morton) Meek
Baculites compressus Say
Inoceramus sp. aff. *barabini* Morton
Pteria (*Pseudoptera*) *fibrosa* Meek & Hayden
Pteria linguiformis Evans & Shumard
Nucula cancellata Meek & Hayden
Yoldia evansi Meek & Hayden
Callista sp.
Geltena (*Mactra*) *gracilis* (Meek & Hayden)
Fusus dakotensis Meek & Hayden
Fasciolaria galpiniana Meek & Hayden
Fasciolaria scarboroughi Meek & Hayden
Lunatia occidentalis Meek & Hayden

This fossiliferous glauconitic sandstone is here designated Zone D. Underlying the sand is a sequence of laminated sandy shale and sand containing essentially the same fauna as the sand, which is designated Zone E. Both Zones D and E are characterized by an abundance of the genera *Mactra* and *Callista*, and the two zones together comprise the most fossiliferous beds in the entire Montana section. A list of fossils obtained from Zone E follows.

[12] L. W. LeRoy, *op. cit.*, p. 86.

Discoscaphites nicolleti (Morton) Meek
Baculites compressus Say
Nucula cancellata Meek & Hayden
Yoldia evansi Meek & Hayden
Callista sp.
Geltena (*Mactra*) *gracilis* (Meek & Hayden)
Inoceramus sp.

The base of Zone E marks the first appearance of anything that resembles a Fox Hills fauna, and is here considered to be the boundary between the world-wide Maestrichtian and Campanian faunal zones.

Below Zone E is a series of drab laminated shale and sandy shale which approaches a thickness of 5,000 feet. This sequence contains many streaks of bentonite, many concretionary bands of ironstone with some cone-in-cone structure, and here and there thin beds of shaly sand. Fossiliferous localities in this section are not common; however, the outcrop is littered with *Inoceramus* prisms. One good fossiliferous horizon was found in section 1 (Fig. 2), about 600 feet below the base of Zone E, which was traceable for some distance along the outcrop. This entire section is designated Zone F, and comprises the greatest part of the upper Pierre as the term is used in this paper. It has yielded the following fauna.

Acanthoscaphites nodosus (Owen) var. *plenus* Meek & Hayden
Baculites compressus Say
Baculites sp.
Inoceramus barabini Morton
Lucina occidentalis Morton
Callista sp.

Below the upper Pierre shale previously described, a sequence of gray to buff glauconitic sand and sandy shale is designated Zone G, and comprises the middle Pierre. This section is distinctly more sandy than the material above and below and contains at least two and probably more well defined sand bodies. The uppermost of these sandstones is 200–300 feet in thickness, and contains numerous fossils. It is buff medium-grained massive to laminated quartz sand, with calcareous cementation and rather extensive limonite staining. The zone as a whole attains a thickness of 1,200–1,500 feet, and contains the following fauna.

Acanthoscaphites sp.
Baculites compressus Say
Baculites sp.
Inoceramus barabini Morton
Inoceramus sp.
Lucina occidentalis Morton

Zone H comprises the lowest unit of the Montana group in this area, and is very uniform dark gray tough fissile shale between 400 and 500 feet thick. It contains thin streaks of bentonite, and has numerous small dense elliptical calcareous concretions. Fish scales are common, and some concretions have yielded numerous specimens of a small baculite which resembles *Baculites asper* Morton. This dark shale constitutes the lower Pierre in the Golden area, and is apparently transitional downward into the buff to gray very calcareous speckled shale of the Niobrara formation.

DESCRIPTION OF INTERMEDIATE SECTIONS

At Ralston Creek (sections 3 and 4, Fig. 2) the basal Laramie sand rests on a fine-grained buff ripple-marked sandstone which is 38 feet thick. This sand rests in turn on a dark clay shale in which was found *Sphenodiscus lenticularis* Owen. The next lower section is poorly exposed and structurally complicated by faulting. However, individual beds were traced across from section 1 as indicated in Figure 2.

North of Van Bibber Creek an exposure of about 50 feet of gray laminated shale and sandy shale contains some bentonite streaks and ferruginous concretionary masses. *Acanthoscaphites nodosus* (Owen) var. *plenus* Meek & Hayden and *Inoceramu barabini* Morton were obtained from one of the concretions. This locality is obviously displaced stratigraphically. The geology of the immediate vicinity is complicated by both faulting and intrusion,[13] and the significance of this occurrence is not known.

At Tucker Gulch (section 6, Fig. 2) a fault separates the Laramie formation from drab upper Pierre shale. The plane of this fault strikes N. 10° E. and dips 50° E. This is the only locality in the area where the Laramie is known to have been affected by fauling.

West of the campus of the Colorado School of Mines (section 7, Fig. 2), the following section was measured.

	Thickness (Feet)
White to buff coarse-grained quartz sand with abundant black tourmaline, limonite stain	12
Laramie-Montana contact	
Drab laminated sandy shale with cone-in-cone concretions, ironstone bands, shell fragments	12
Drab to gray laminated sandy shale and shale with cone-in-cone concretions, streaks of buff siltstone	208
Buff laminated silty fine-grained glauconitic fossiliferous sandstone with *Discoscaphites* sp., *Baculites compressus, Pteria (Pseudoptera) fibrosa, Pteria linguiformis, Nucula cancellata, Callista* sp., *Geltena (Mactra) gracilis, Fasciolaria galpiniana*	49
Drab laminated shale and sandy shale	800
Dark gray to drab shale with cone-in-cone concretions, abundant selenite crystals, *Baculites compressus, Inoceramus* sp., *Lucina occidentalis*	50
Drab laminated shale	150
Fault	

The following section was measured at Deadman Gulch, just south of Golden (section 8, Fig. 2).

	Thickness (Feet)
Buff medium-grained quartz sand with black tourmaline, clay pebbles, small liminitic concretions	2
Laramie-Montana contact	
Drab laminated very lignitic sandy shale	41
Dark gray sandy shale with abundant brown and black lignite, few fossil imprints	5

[13] W. A. Waldschmidt, "The Table Mountain Lavas and Related Igneous Rocks near Golden, Colorado," *Colorado School Mines Quar.*, Vol. 34, No. 3 (1939).

	Thickness (Feet)
Buff dense fine-grained fossiliferous siltstone with small calcareous concretions, *Discoscaphites nicolleti, Nucula cancellata, Yoldia evansi, Lucina subundata, Dentalium* sp., *Cylichna volvaria, Lunatia occidentalis*	40
Transition zone from sandy shale to sand	3
Buff fine-grained ripple-marked laminated very lignitic sand with large ferruginous concretions	34
Covered	

On the west flank of Green Mountain (section 9, Fig. 2) the following section was obtained.

	Thickness (Feet)
White coarse-grained sand with black tourmaline	32
Laramie-Montana contact	
Drab laminated shale and sandy shale	200
Buff fine-grained laminated silty sand	18
Dull gray to drab laminated silty shale	326
Greenish gray very glauconitic fine- to medium-grained fossiliferous sand with *Discoscaphites conradi, Discoscaphites nicolleti, Baculites compressus, Nucula cancellata, Callista* sp., *Geltena* (*Mactra*) *gracilis, Lunatia* sp., *Fasciolaria scarboroughi*	24
Covered	

Sections 10, 11, and 12 (Fig. 2) have been combined into the following composite section.

	Thickness (Feet)
White coarse-grained massive quartz sand	60
Laramie-Montana contact	
Dark gray laminated very lignitic sandy shale	20
Gray to buff laminated clay shale with *Nucula cancellata, Yoldia evansi,* fish scales	63
Fine-grained buff laminated ripple-marked sand with large ferruginous concretions, much comminuted plant material, shell fragments	48
Drab laminated shale and sandy shale	437
Buff fine-grained laminated silty sand, very calcareous, with *Discoscaphites* sp.	16
Covered	360
Drab laminated sandy shale with *Callista* sp., *Geltena* (*Mactra*) *gracilis*	32
Covered	

Table I shows zone thicknesses at each locality, as determined from the sections previously cited.

TABLE I

ZONE THICKNESS IN FEET

Section Number (Figure 2)

Zone	*1*	*3*	*6*	*7*	*8*	*9*	*10*	*12*	*Bear Creek Composite*
A	0	0	0	0	88	0	78	83	53
B	33	36	0	0	34	0	40	48	34
C	910	No	0	220	No	544	78	453	848
D	42	No	0	49	No	24	No	No	53

Note: "No" means not observed due to non-exposure or faulting below known Montana.

These determinations have been combined into a schematic cross section (Fig. 4) which shows graphically the zonation at each section.

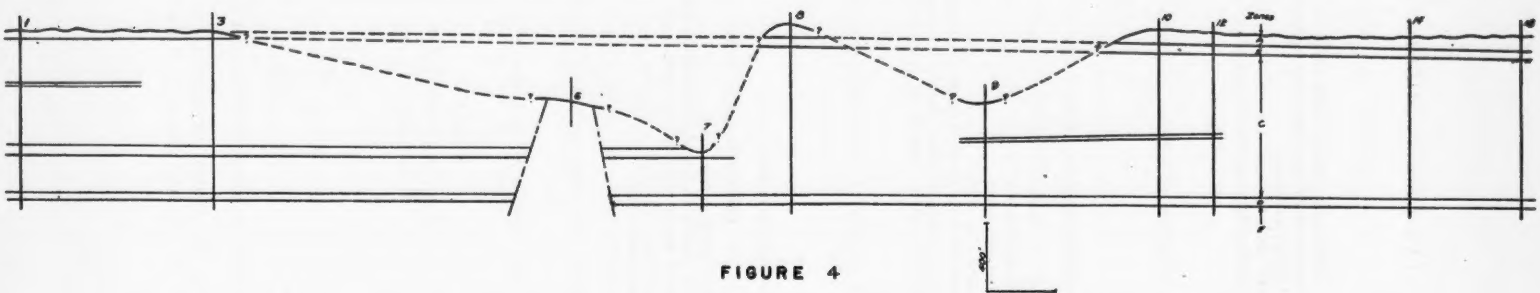

FIGURE 4

FIG. 4.—Schematic north-south section showing zonation (A, B, C, D, E) at each vertical section. Numbers on sections indicate locations shown in Figure 2.

TABLE II

NOMENCLATURE OF MONTANA GROUP IN EASTERN COLORADO

Zones in Golden Area	6 *Emmons, Cross & Eldridge*	7 *Henderson*	1 *Ball*	11 *Lavington*	4 *Dane, Pierce & Reeside*	17 *Rankin*	19 *Van Tuyl et al.*	12 *LeRoy*	*This Paper*
A	Fox Hills	Fox Hills	Fox Hills	Fox Hills	Fox Hills	Fox Hills	Fox Hills	Fox Hills	Fox Hills
B		Milliken						Milliken	Milliken
C				Transition Zone					
D									
E				Cone-in-cone Zone		Upper (Lewis)			Upper Pierre
F	Pierre	Pierre	Lewis		Pierre			Pierre	
G	Sandy Zone	Hygiene Sand	Mesa Verde: Richland Larimer Rocky Ridge Terry Hygiene	Tepee Zone Rusty Zone		Middle (Hygiene)	Pierre		Middle Pierre
H			Steele	Barren Zone	Sharon Springs Shale	Lower (Steele)			Lower Pierre

AGE ASSIGNMENT AND CORRELATION

According to Reeside[14] the ammonites *Discoscaphites conradi* (Morton) Meek and *Discoscaphites nicoletti* (Morton) Meek indicate Maestrichtian age, whereas *Acanthoscaphites nodosus* (Owen) var. *plenus* Meek & Hayden indicates Campanian age. Further, *Sphenodiscus lenticularis* Owen is generally conceded to indicate Maestrichtian age. Thus, it is possible to divide the Montana group into a Campanian and a Maestrichtian part on the basis of ammonites. This dividing line coincides with the base of Zone E. This horizon is further marked by the appearance of a varied molluscan fauna, including abundant specimens of the genera *Geltena* (*Mactra*) and *Callista*.

The faunal assemblage found in Zones D and E, although Maestrichtian in age, shows an intermingling of upper Pierre fossils with those considered to indicate Fox Hills of the type locality. Thus Zones D and E, with a total known thickness of 360 feet, are considered to represent the transitional beds between typical Pierre and typical Fox Hills in the upper Missouri country. Zone C contains a Fox Hills fauna. The base of Zone B, which is the base of the Fox Hills as restricted by Lovering *et al.*,[15] is thus seen to lie 910 feet above the top of the transition zone, and 1,270 feet above the first occurrence in the section of a Fox Hills fauna. It is apparent that the base of the restricted Fox Hills is not a time line, although in limited areas it is of unquestioned value in mapping. Little seems to be gained by using the term Fox Hills in either its restricted or unrestricted sense in this area. Henderson[16] and Mather *et al.*,[17] have been emphatic in pointing out the undesirability of applying the term Fox Hills in northeastern Colorado.

The restricted Fox Hills comprises Zones A and B, with a maximum observed thickness of 131 feet. Zone B is the equivalent of some part of the Milliken sandstone, and it seems wholly permissible to apply the name Milliken to this unit in this area.

The Pierre shale includes all the strata herein assigned to Zones C, D, E, F, G, and H. Table II is a tabulation of the names applied to the Montana group in eastern Colorado by various authors. The writer feels that if the correlations of the Pierre with the Lewis, Mesaverde, Steele sequence of Wyoming (as indicated in Table II by Ball and Rankin) can be justified paleontologically, they should be applied throughout eastern Colorado. As Bartram[18] points out, the Upper Creta-

[14] J. B. Reeside, Jr., "The Scaphites, an Upper Cretaceous Ammonite Group," *U. S. Geol. Survey Prof. Paper 150B* (1927).

[15] T. S. Lovering, H. A. Aurand, C. S. Lavington, and J. H. Wilson, *op. cit.*, p. 702.

[16] J. Henderson, "The Cretaceous Formations of the Northeast Colorado Plains," *Colorado Geol. Survey Bull. 19* (1920).

[17] K. F. Mather, J. Gilluly, and R. G. Lusk, "Oil Possibilities of Northeastern Colorado," *U. S. Geol. Survey Bull. 796B* (1928).

[18] J. G. Bartram, "Upper Cretaceous of Rocky Mountain Area," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 7 (1937).

TABLE III

CHECK LIST OF FOSSILS FROM MONTANA GROUP IN GOLDEN-MORRISON AREA, JEFFERSON COUNTY, COLORADO

	Maestrichtian					*Campanian*		
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
Acanthoscaphites nodosus (Owen) var. *Plenus* Meek & Hayden						x	x	
Baculites sp. aff. *Asper* Morton		x						x
Baculites compressus Say			x	x	x	x	x	
Baculites sp.					x	x		
Discoscaphites conradi (Morton) Meek				x				
Discoscaphites nicolleti (Morton) Meek	x		x	x	x			
Sphenodiscus lenticularis Owen			x					
Callista sp.				x	x			
Callistra sp.						x		
Geltena (*Mactra*) *gracilis* (Meek & Hayden)				x	x			
Inoceramus barabini Morton				x	x	x	x	
Inoceramus sp.						x	x	
Leptosolen sp.			x					
Lucina occidentalis Morton						x	x	
Lucina subundata Meek & Hayden	x		x					
Nucula cancellata Meek & Hayden	x		x	x	x			
Nuculana sp.			x					
Pteria (*Pseudoptera*) *fibrosa* Meek & Hayden			x	x				
Pteria linguiformis Evans & Shumard			x	x				
Pteria nebrascana Evans & Shumard		x	x					
Tellina sp.	x	x	x					
Yoldia evansi Meek & Hayden	x		x	x	x			
Dentalium sp.	x		x					
Cylichna volvaria Meek & Hayden	x							
Fasciolaria galpiniana Meek & Hayden				x				
Fasciolaria scarboroughi Meek & Hayden				x				
Fusus dakotensis Meek & Hayden				x				
Lunatia occidentalis Meek & Hayden	x		x	x				
Lunatia sp. aff. *subcrassa* Meek & Hayden				x				

ceous of the Rocky Mountains is weighted down with a plethora of stratigraphic names, and any useful simplification of the nomenclature system is to be desired. Until such definite correlation can be made, however, Rankin's division of the Pierre into upper, middle and lower appears to be the best. As the term "Hygiene" has been restricted to the lowest of a series of sandstones in the middle third of the Pierre, it can not be used to designate the middle Pierre.

Table III is a check-list of the Montana fossils found by the writer.

CONCLUSIONS

It has been demonstrated conclusively that the basal Laramie sand rests on different zones of the Montana group at different localities within the area. Locally as much as 800 feet of section is missing between the Laramie and the upper Pierre, as is shown in Figure 4. Although the possibility of faulting as an explanation of the short sections has not been entirely eliminated, the Laramie-Montana contact is exposed at many localities within the area, and only at section

6 (Fig. 2) is there definite evidence of faulting. The writer believes that most, if not all, of the missing section is absent due to pre-Laramie erosion. Certainly some of it is. The following observations are considered in favor of this interpretation.

1. Well defined stratigraphic zones are locally absent at the contact.

2. There is a distinct lithological and depositional change from Montana to Laramie.

3. The contact is sharp and distinct.

4. The Fox Hills in the Golden area is considerably thinner than it is at other localities in eastern Colorado.

5. The composition and textural relationships of the Laramie strata indicate that during Laramie deposition the Golden area was the site of a major channel or delta.

6. The nature of the sediments in the Laramie suggests that not very far west there was an area within which pre-existing sedimentary rocks were exposed to erosion.

It is probable that the disconformity between the Laramie and the Montana is somewhat restricted in occurrence, since Dobbin and Reeside[19] have shown that farther north the Fox Hills and Lance are conformable. However, the existence of a disconformity even in a limited area is of some importance, since it indicates that there was considerable movement of the Front Range positive element prior to Laramie deposition.

Lovering,[20] in 1929, made the following statement.

> . . . The middle of Pierre time saw the end of subsidence and the initiation of uplift which soon pushed the central part of the Front Range Highland above the sea and exposed the recently deposited shales to erosion. These were reworked into the upper part of the marine Cretaceous, and the pre-Cambrian core was re-exposed as a source of sediments when the Laramie sands were forming. . . .

The writer is in general agreement with the foregoing statement; however, he believes that much of the sediment in the Laramie sands was derived from the Dakota. The change from the dark gray non-sandy lower Pierre shales to the very lignitic sands and sandy shales of the middle and upper Pierre indicates an important change in the source of the sediments, and further substantiates Lovering's views.

In the course of the field work, it became apparent to the writer that the structure of the Golden area is much more complicated than is shown on the current map of the area.[21] It is hoped that the zonation presented here may be

[19] C. E. Dobbin and J. B. Reeside, Jr., "The Contact of the Fox Hills and Lance Formations," *U. S. Geol. Survey Prof. Paper 158* (1929).

[20] T. S. Lovering, "Geologic History of the Front Range, Colorado," *Proc. Colorado Sci. Soc.*, Vol. 12, No. 4 (1929).

[21] F. M. Van Tuyl, J. H. Johnson, W. A. Waldschmidt, James Boyd, and Ben H. Parker, "Guide to the Geology of the Golden Area," *Colorado School Mines Quar.*, Vol. 34, No. 3 (1939). Map in pocket.

useful in unravelling the structural details of the area, since most of the faulting is localized within the Montana outcrop. The structural complexity of the Golden area is due to two factors, faulting and intrusion, and both of these seem to be controlled by the relative incompetency of the Montana strata.

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OCCURRENCE OF COMANCHE ROCKS IN BLACK RIVER VALLEY, NEW MEXICO[1]

WALTER B. LANG[2]
Washington, D. C.

ABSTRACT

The discovery of Comanche fossils in Black River Valley provides a means for more accurately defining the position of the Comanche shoreline in southeastern New Mexico. An explanation is offered for the anomalous occurrence of these fossils and one which may help to clarify previous misconceptions of the geology of the area. A brief reference is made to related early geologic explorations in the region.

In the valley of Black River, near the center of the east side of the NW. ¼ of Sec. 31, T. 25 S., R. 25 E., Eddy County, New Mexico, and about 200 feet southeast of the highway (U. S. 62, State 180) is a patch of loose gravel and rock débris resting on a top soil of gypsite. This débris, which is likely to be overlooked by anyone not purposely in search of it, was turned up by the Army in 1943 when grading a new road, and it was found by a party of Superior Oil Company geologists on a field trip in 1944.[3] This material is of interest because it is geologically anomalous to the area. Here and for miles around, the Castile formation of Permian age, where not covered by a remnant of Rustler dolomite, the Quaternary Gatuña formation, or more recent valley deposits, is exposed at the surface.

Scattered about within a circle approximately 200 feet in diameter are fragments of sandstone and limestone. Many of the fragments are fossiliferous. Though the fossils are abundant they are limited in variety, as becomes apparent when the ground is carefully combed for every variant form. R. W. Imlay examined a collection made here and listed the following forms.

Anorthopygus n. sp.
Gryphaea corrugata (Say)
Neithea texana (Roemer)
Opis? sp.
Protocardia texana (Conrad)

Imlay states

> *Gryphaea corrugata* Say ranges through the Duck Creek and Kiamichi. The new species of the echinoid genus *Anorthopygus* has been identified by C. W. Cooke, who notes that it has been found in the Duck Creek and Fort Worth. Furthermore, the rock matrix resembles the Duck Creek limestone.

These identifications place the horizon of the strata from which the fragments were derived at the base of the Washita group of the Comanche series. The Kiamichi formation, which was formerly placed at the base of the Washita group, is now placed by the United States Geological Survey at the top of the underlying Fredericksburg group of the Comanche series.

[1] Manuscript received, May 21, 1947. Published by permission of the director of the United States Geological Survey.

[2] United States Geological Survey.

[3] Personal communication, Robert R. Wheeler.
There were reports at large in the field about 1927 of the finding of Cretaceous fossils in the vicinity of Rattlesnake Canyon Draw, New Mexico.

A specimen of every sedimentary rock type in the débris was collected and examined. With the exception of the quartzose gravels the sedimentary rocks represent four types. (1) Coarse- to medium-grained sandstones, some a little conglomeratic containing inclusions of limestone and marl, rounded pebbles of milky and smoky quartz. This rock weathers to a lumpy surface. The color is grayish, in places showing a glassy reflection. The grains are subrounded and spheroidal and show frosting. The grains average 1/50 inch, and some associated pebbles are as much as 2/5 inch in diameter. A few of them are rose, brown, to black in color.

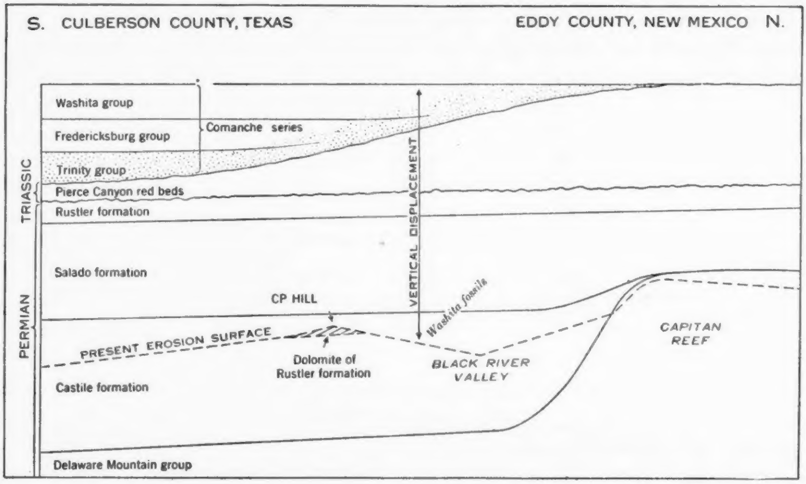

FIG. 1.—Diagrammatic section from Cottonwood Draw, Culberson County, Texas, to Walnut Canyon, Eddy County, New Mexico, to show the location of Washita fossils on present erosion surface and their anomalous stratigraphic position. Whether all intervening formations or all of any of them were present when Comanche rocks were deposited is a question. It is therefore not known what the vertical intercept amounted to in feet at close of Comanche time. The fact that part of Rustler formation where it rests on beds of Castile is also out of place is significant.

They are all well compacted and cemented by calcium carbonate, but the rock still remains somewhat friable. Stratification is indicated by arrangement of the coarser fragments. (2) Very fine-grained, dense, calcareous sandstone; siltstone. The color ranges from pale buff, through light olive-drab to dull brick-red. Some of the red material has gray-green reduction spots very similar to the Pierce Canyon redbeds of Triassic age, but the presence of Cretaceous fossils in other pieces of rock similarly spotted eliminates the possibility of this age. Buff sandstones show cross-bedding. The olive-drab rock is dense and finely laminar, and very similar to the same colored beds of the Kiamichi formation cropping out in Rogers Draw, New Mexico. (3) Light gray, brownish and reddish, highly fossiliferous sandy limestone. Much of the fossil material is fragmental but a few fossils are well preserved. (4) Dense fine-grained, fossiliferous, light pearl-gray

limestone. Though somewhat marly the non-fossiliferous matrix resembles unglazed porcelain.

It is quite apparent from the examination of both the lithologic and paleontologic material that the whole suite of specimens is Washita in age. No other rocks are present except the quartzose gravels.

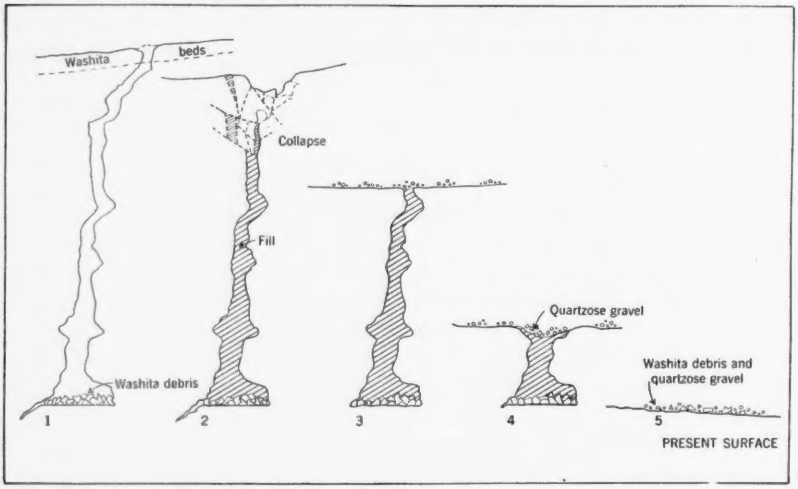

FIG 2.—Series of schematic diagrams to illustrate a possible way in which Washita débris may have been captured and preserved.

1. Development of solution channel and capture of Washita débris when Washita rocks were being eroded.
2. Filling and collapse of solution channel.
3. Erosion and continued lowering of valley floor.
4. Accumulation of quartzose gravel in depression formed in softer material of fill.
5. Release of Washita débris and quartzose gravel on present erosion surface.

This Comanche material is stratigraphically out of place (Fig. 1). Approximately 2 miles southeast, in Sec. 5, T. 26 S., R. 25 E., the westernmost remnant of the lower part of the Rustler formation of Permian age in New Mexico rests on the Castile formation and forms the cap of CP Hill. The altitude of CP Hill is 3,855 feet and that of the Washita fossils is 3,720 feet, which places them 135 feet below the top of the hill. Though the fossils lie on the updip side of the hill (Fig. 1), they are at a much lower altitude than even those beds of the Castile which are found under CP Hill, and thus are well within the stratigraphic interval of the Castile formation. The most likely explanation for the unconventional position and fragmental character of these Washita rocks is that they were trapped at some time during the early development of Black River Valley in a deep sink or cavernous channel which later collapsed, and they have been preserved there while the enclosing rocks were eroded away, lowering the valley

floor to its present position (Fig. 2). The ubiquitous quartzose gravels were accumulated probably by surface drainage in a depression formed in channel fill in the gypsum during a later stage of the development of Black River Valley.

The discovery of rocks and fossils in discordant stratigraphic position is not at all singular in this region of soluble formations. Udden[4] was induced to assign a Cretaceous age to the Castile and Rustler formations on finding Cretaceous Foraminifera in well cuttings from depths of 140 to 265 feet below the surface at a time when the position of these formations in the geologic column was none too well established. The well was located about a mile east of Rustler Spring, where the basal part of the Rustler formation, which makes up the Rustler Hills and the Screwbean Hills on the north, caps the Castile formation. Solution openings which had formed in these rocks provided a place for lodgment of fossils washed out of the overlying Comanche rocks. Conditions favoring such events are as prevalent to-day as they were in the past. Hardly more than a mile away from the deposit of Comanche débris is Bottomless or Azul Lake, a water-filled sink hole 45 feet deep in the Castile formation, where loose rocks on the surface may now be washed in and engulfed after the manner proposed to explain the preservation of the Comanche rocks and fossils. At the mouth of Slaughter Canyon in the Guadalupe Mountains, ground water flowing beneath the canyon floor has dissolved out of the Castile a large channel which collapsed to form an enormous sink. In the Pecos Valley near Arno, Texas, a well was drilled in 1922 to the depth of 1,000 feet and all in valley fill. This was such an unexpected occurrence at the time that the fact was subject to doubt. Since then a number of wells have been drilled along the trend of the Pecos River from the vicinity of Mentone to Grand Falls, Texas, in which there was found nothing but fill from the surface to depths of 1,165 to 1,730 feet.[5] Even a few wells as much as 10 or more miles east and west of the river penetrated valley fill to comparable depths. The drillers of the Wesner well (Sec. 25, Blk. 101, Culberson County, Texas) in 1923 encountered a cavity so large that the string of tools laid over in it and they were forced to stuff down the well all manner of things they could find about the place in order to align the bit. The Pure Oil Company in 1926 drilled a well near Delaware Springs (Sec. 12, Blk. 63, T. 2, Culberson County, Texas). In the course of drilling the bit entered a large cavity, which was bypassed only with considerable trouble. Such examples of solution openings, both filled and unfilled, in the Permian rocks of this area are legion.

The occurrence of these Comanche fossils in Black River Valley is a valuable

[4] J. A. Udden, "The Age of the Castile Gypsum and the Rustler Springs Formation," *Amer. Jour. Sci.*, Vol. 40 (1915), pp. 151–56.

[5] The finding of gravel and chert in samples from below the Rustler formation and the overlying valley fill in wells at depths of more than 2300 feet suggests solution channeling and refilling with surface material as the explanation for their occurrence rather than as cavings, especially in those wells where casing was set below the base of the valley fill or in the Rustler formation. Such is the opinion of both Edgar Kraus and N. B. Winter on examination of samples from the wells. Personal communication.

Though in New Mexico the evidence for trash-filling of openings in and below the Rustler is indisputable it is not found at so great depths below the surface as in Texas.

aid in fixing with greater certainty the limits of the Comanche sea, and confirms a supposition previously stated[6] that the basal sandstones representing the marginal deposits of the Comanche sea ascend stratigraphically about the Guadalupe-Sacramento area from Trinity to Washita time and that the Comanche sea had made the greatest advance from the south and east in Washita time. The identification of material in Black River Valley that is representative only of the Washita may be more significant than accidental. Outcrops of Comanche rocks nearest to Black River Valley are 50 miles south by east in Cottonwood Draw, Reeves and Culberson counties, Texas, where all three subdivisions of the series are present. It seems almost certain that, if any of the highly fossiliferous members of the Fredericksburg group had been deposited over this part of Black River Valley, some representatives of these rocks would have appeared in the assemblage.

One hundred miles distant from Black River Valley, in the Four Lakes area (Sec. 32, T. 10 S., R. 34 E.) northwest of Tatum in Lea County, and 150 miles distant, near Rogers (T. 3 S., R. 36 E.), Roosevelt County, New Mexico, Kiamichi rocks crop out around the margins of depressions in the Llano Estacado (Fig. 3). In Rogers Draw the limestones of the Kiamichi formation overlie a thin basal sandy conglomerate, which in turn rests on Triassic rocks. No Comanche rocks have been found north of a line from Cornudas Mountain to Black River Valley or west of the line from there to Four Lakes and Rogers. At these four locations the rocks are either Kiamichi or Duck Creek in age, and no other Comanche rocks are present. Rocks of Comanche age are found northward along the Rocky Mountain front as the Purgatoire formation with a strong westward-extending reentrant in the vicinity of Las Vegas, New Mexico. From this distribution of Comanche rocks it is apparent that the Comanche sea made its greatest advance into West Texas and southeastern New Mexico in Kiamichi and Duck Creek time and subsequently receded, and that the Guadalupe-Sacramento area remained sufficiently positive with respect to all the Comanche incursions to prevent its submergence. It was not until upper Cretaceous time that a Cretaceous sea covered at least a part of this area.[6a] It is also quite possible that the superior position of the Guadalupe-Sacramento area in Comanche time may be due in part not only to structural movement but also to differential erosion in pre-Comanche time.

Though Jules Marcou's report[7] on the stratigraphy of this region antedates that of George G. Shumard, it was not made from a personal reconnaissance.

[6] W. B. Lang, "Permian Formations of the Pecos Valley of New Mexico and Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21 (1937), p. 897.

[6a] In the Fort Stanton-Indian Divide country, southwest of the Capitan Mountains of New Mexico, and in the mesas west of the Carrizo and Jicarilla mountains, the basal Dakota sandstone of the Upper Cretaceous rests on the eroded surface of the Dockum group of the Triassic.

[7] Jules Marcou, "Geological Notes of a Survey of the Country between Preston, Red River, and El Paso, Rio Grande del Norte," *House Document 129*, Washington (1855). Transmitted September 21, 1854.

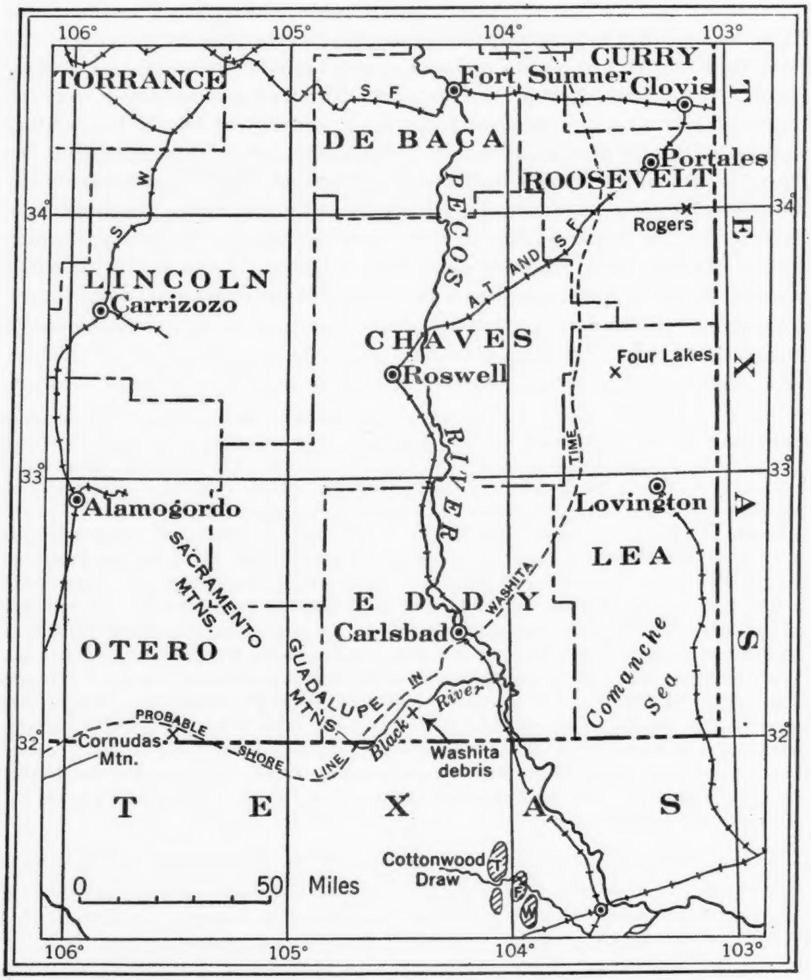

FIG. 3.—Map of southeastern New Mexico and adjoining Texas showing probable maximum position of Comanche shoreline, location of Washita débris in Black River Valley, and locations of other Comanche deposits. *T*—Trinity. *F*—Fredericksburg. *W*—Washita. *X*—Comanche outcrops in Roosevelt and Lea counties, New Mexico.

Capt. John Pope traversed the area in 1853 and Marcou's report was based on the notes and specimens collected by Pope. Marcou recognized the dolomitic character of the strata exposed at the junction of Delaware Creek with the Pecos River.

Shumard was the first to make a report on the geology of the middle Pecos River when in 1855 as a member of Captain Pope's expedition he traveled up the Pecos from Live Oak Creek in Crockett County, Texas, to the mouth of Delaware Creek near the Texas-New Mexico boundary. Shumard collected fossils from the abundant exposures of Comanche rocks in the canyon cut by the Pecos River across the Edwards plateau. He reported the appearance of Permian fossils in the river gravels first seen near Toyah Creek but strangely makes no mention of the Triassic outcrops as such, although Roemer[8] had made known the presence of Triassic rocks in western Texas in 1852. As he approached the Delaware camp site on May 26, 1855, Shumard noticed in and about the course of the Pecos tumbled masses of limestone which he recorded as Cretaceous. Though he remained three months in reconnaissance of the vicinity of the camp before journeying westward to the Rio Grande, nothing subsequently occurred to alter his previous opinion. In his journal[9] Shumard described the rocks as follows.

All the rocks of this vicinity, save the limestone [his Cretaceous is the Culebra dolomite member of Rustler formation] noticed on our last day's journey, were found to differ somewhat in general character from those already described. The limestone here attains a thickness of over a hundred feet [in the Pecos River, seldom more than 40 feet, though slumping and a caliche cap often give the impression of greater thickness; to the west the dolomite thickens], exhibiting itself chiefly in the form of flattened conical hills and rough cliffs, sometimes with vertical faces, and in places rising above the creek or river bed to the height of fifty or sixty feet. The rock is usually hard, of a light cream color, earthy texture, and contains numerous spheroidal cavities, from a fourth to a half inch in diameter, which are sometimes partially filled with loose ferruginous earth. [This is an excellent description of the Culebra dolomite member of the Rustler formation.] In one locality the exposed edges of the strata were covered with an incrustation of salt, a fourth of an inch thick. The limestone forms the bed of the Pecos River, and here gives rise to a succession of rapids. Fourteen miles to the east the same limestone [caliche] becomes much softer, lighter colored, and resembles impure chalk, but does not exceed in thickness thirteen or fourteen feet. Fossils are rare in it [meaning both the dolomite and the caliche]. In a few instances I obtained imperfect specimens of *Exogyra* [*Gryphaea?*] *pitcheri* and *Janira* [*Neithia*] *quadricostata*.

Shumard is not alone in having become a victim to the subtle complexities of this region. As a pioneer, traveling for 6 days up the broad flat floodplain of the Pecos without seeing an outcrop of Cretaceous rocks, it is easy to understand that he should give credence to the fossils he had discovered. Both rocks are similar in appearance and, as the dolomite with few exceptions is non-fossiliferous, he had nothing more to serve him as a guide. The fact that his specimens were imperfect leads one to assume that they were float which may have become attached to Culebra rocks by the formation of hard river caliche. From this we may infer that the Pecos river gravels had, and may still hold, Comanche rocks and fossils, remnants of an earlier period of erosion; a precursor of the prolific display of Permian cobbles and gravels now lining the course of the Pecos River in New Mexico.

[8] Ferdinand Roemer, *The Cretaceous Formation of Texas* (1852).

[9] G. G. Shumard, *The Geology of Western Texas*, p. 88. Austin (1886).

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TERMINOLOGY FOR INSOLUBLE RESIDUES[1]

H. A. IRELAND[2] AND OTHERS[3]
Midland, Texas

ABSTRACT

The rapid development of the use of insoluble residues for correlation since 1940 has resulted in a diverse terminology which needs standardization. A group of geologists familiar with residue work agreed in conference upon terminology and definitions, and developed the outline included in this article. The contents of the outline are based on description rather than on genesis, since the genesis of many constituents of residues is not known or is controversial. The outline and its contents are submitted as a guide to new workers and as a common source of agreement among those most familiar with correlation and identification using insoluble residues. The term insoluble residues is herein restricted to the residues from digestion in dilute hydrochloric acid.

The publication of H. S. McQueen in 1931[4] established methods of preparation, terminology, and practical application of insoluble residues for subsurface and surface correlation and identification of calcareous rocks. Nearly all subsequent workers during the following 10 years visited Rolla, Missouri, for introduction to McQueen's methods and procedure. Early work prior to 1938 applying residue examination to subsurface geology was done by Littlefield,[5] Hiestand[6] and Ockerman[7] in Kansas, Ireland[8] in Oklahoma, and Burpee and Wilgus[9] in New Mexico. Early workers on residues from surface beds were Ireland,[10] Martin[11] and Merritt.[12]

[1] Manuscript received, April 11, 1947.

[2] Standard Oil Company of Texas. Chairman of the insoluble residue conference.

[3] Other participants in standardization of terminology for insoluble residues: A. L. Repecka, Superior Oil Company, W. A. Waldschmidt, Argo Oil Corporation, Donald Bell, Shell Oil Company, E. W. Vanderpool, Midland, Texas; Leo Hendricks, Texas Christian University, Fort Worth, Texas; W. E. Ham, Oklahoma Geological Survey, Norman, Oklahoma; Lloyd Haseltine, Magnolia Petroleum Company, Wichita Falls, Texas; A. J. Crowley, The Texas Company, Denver, Colorado; L. E. Workman, Illinois Geological Survey, Urbana, Illinois; John Groskopf, Missouri Geological Survey, Rolla, Missouri; Robert F. Walters, Gulf Oil Corporation, Tulsa, Oklahoma.

[4] H. S. McQueen, "Insoluble Residues as a Guide to Stratigraphic Study," *Missouri Bur. Geol. and Mines 56th Bien. Rept.* (1931). Appendix I, 32 pp.

[5] Max Littlefield, Gulf Oil Corporation. (Unpublished work.)

[6] T. C. Hiestand, "Studies of Insoluble Residues from 'Mississippi Lime' of Central Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22 (1938), pp. 1588–99.

[7] J. W. Ockerman, "Insoluble Residues of the Hunton and Viola Limestones of Kansas," *Jour. Sed. Petrol.*, Vol. 1 (1931), pp. 43–46.

[8] H. A. Ireland, "Use of Insoluble Residues for Correlation in Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20 (1936), pp. 1086–1121.

[9] G. E. Burpee and W. L. Wilgus, "Insoluble Residue Methods and Their Application to Oil Exploitation Problems," *Mining and Metallurgy*, Vol. 16 (1935), pp. 418–20.

[10] H. A. Ireland, *op. cit.*

[11] H. G. Martin, "Insoluble Residue Studies of Missippian Limestones in Indiana," *Indiana Dept. Conserv. Pub. 101* (1931). 37 pp.
———, "The Insoluble Residues of Some Mississippian Limestones of Western Kentucky," *Kentucky Geol. Survey*, Ser. 6, Vol. 41 (1931), pp. 129–89.

[12] C. A. Merritt and C. E. Decker, "Physical Characteristics of the Arbuckle Limestone," *Oklahoma Geol. Survey Cir. 15* (1928). 54 pp.

After 1938 many papers, reports, abstracts, and unpublished work on surface and subsurface studies indicate the increased interest and use of residues for correlation and identification of beds. The examination of residues for petroleum geology was not widely used until about 1940.[13] By 1946 the State geological surveys of Illinois, Indiana, Kentucky, Tennessee, Missouri, Nebraska, Kansas, Oklahoma, and Texas had issued publications based wholly or in part on surface and subsurface data from insoluble residues. The United States Geological Survey recently issued three publications based on subsurface residue data.[14] Most of the terminology for residues in Texas areas was developed independently of the usage of McQueen, partly because of needs for modification, and also because of independent thinking. Most of the usage has never been published and considerable diversity of nomenclature has developed.

The increase in the number of workers using residues resulted in a diversity of terminology in publications and unpublished practical usage. The table published by Cole[15] is applied only to the Ellenburger formation of Texas but residue study may be applied to most of the calcareous formations of central United States. The terms are good but most of them are different from those used by workers outside Texas and the need for standardization is apparent. Terminology in future publications and usage of unpublished terms will undoubtedly increase and compound the diversity of descriptions and terminology for insoluble residues unless they are standardized. At the present time the technique is at a stage where standardization will not be difficult but diverse usage, especially unpublished usage, will make standardization more difficult as time progresses. Standardization is essential for the scientific and practical advancement of the use of residues.

In June, 1946, a 2-day conference was arranged in Midland, Texas, by H. A. Ireland for the purpose of standardizing the terminology used for insoluble residues. Geologists in the central United States who were active or known to be interested in residue work were invited. Special acknowledgment is due Leo Hendricks and W. A. Waldschmidt in developing the conference and in the work

[13] K. E. Born and H. B. Burwell, "Geology and Petroleum Resources of Clay County, Tennessee," *Tennessee Dept. Conserv. Div. Geol. Bull. 47* (1939), pp. 20–57.

M. G. Cheney, "Geology of North-Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), pp. 65–118.

Leo Hendricks, "Subsurface Divisions of the Ellenburger in North-Central Texas," *Univ. Texas Bur. Econ. Geol. Bull. 3945* (1940), pp. 923–68.

Taylor Cole, "Subsurface Study of Ellenburger Formation in West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26 (1942), pp. 1398–1409.

A. J. Crowley and Leo Hendricks, "Lower Ordovician and Upper Cambrian Subsurface Divisions in North-Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29 (1945), pp. 413–25.

[14] H. A. Ireland, "Correlation and Subdivision of Subsurface Lower Ordovician and Upper Cambrian Rocks in Northeastern Oklahoma," *U. S. Geol. Survey Chart 5*, Oil and Gas Investig. Ser., with text (1944).

———, "Maps of Northeastern Oklahoma and Parts of Adjacent States Showing the Thickness and Subsurface Distribution of Lower Ordovician and Upper Cambrian Rocks below the Simpson Group," *U. S. Geological Survey Prelim. Map 52*, Oil and Gas Investig. Ser., with text (1946).

A. J. Crowley and Leo Hendricks, *op. cit.* (released for outside publication).

[15] Taylor Cole, *op. cit.*, pp. 1400–01.

following the conference. Most of the participants brought slides of various types of residues labelled according to their own terminology. Residues were examined, discussed, and defined, and an organized outline was composed by those present. Those unable to attend were sent copies of the final results of the conference and after several revised editions the outline, definitions, and terminology published herein evolved. The definitions and terms published are not the opinion or usage of any one person. They are written word for word as agreed upon at the conference or as revised by a later conference and correspondence. It is hoped that the agreement by this group of active and experienced workers with insoluble residues will establish usage of the terminology and also serve new workers who may utilize insoluble residues as a means of correlation and identification.

Failure to use the terminology as established will destroy the value of the conference and again throw the study of residues into a chaos of diverse terms which will prevent progress and understanding. The reluctance of individuals to alter familiar and personal designations of terms will prevent the complete establishment of common terms judged preferable by those most qualified to judge. The conference was developed to forestall the vexing situation which has arisen in other fields where coordination and standardization were delayed until too late.

OUTLINE

The introduction to this article was written by the chairman of the conference, but the outline and definitions of terms are a collaboration of the participants of the conference. The writer assumes responsibility for introductory statements not part of the outline, and joint responsibility for the contents of the outline.

Terminology for the most part, follows the precedent of the Missouri Geological Survey, to which so much is owed for establishment of residues as a method. It is believed that their descriptions should be used as criterion because of the long usage and repeated appearance in the literature. Some modifications are made in the light of new knowledge and the experience of many workers. The significant changes are the use of the word "dolomoldic" for "dolocastic," "granular" for "crystalline"; "lacy" is restricted to fragments with irregular openings while "skeletal" is applied to fragments with rhombohedral openings.

The terminology is based on description rather than genesis of the residues because the genesis of many constituents is unknown, vague, or controversial. Residues are frequently called "siliceous residues," a designation which should be discarded. Many residues such as glauconite, pyrite, shale fragments, iron pellets, sphalerite, anhydrite, gypsum, and several other minerals are not siliceous.

The outline is organized according to the major constituents under headings of quartz, chert, argillaceous material, arenaceous material, anhydrite, gypsum, and accessory minerals and other constituents. A term is defined the first time it appears in the outline. The first-order headings are all nouns and the subheads are descriptive adjectives. Multiple subheads give additional specific and detailed

- QUARTZ
  - Euhedral
  - Subhedral
    - Loose
    - Drusy
    - Granulated
      - Fine
        - Unmodified
        - Lacy
        - Drusy
        - Dolomoldic
          - Skeletal
          - Abundant
          - Scattered
        - Dolomorphic
        - Oolitic
          - Concentric
          - Radiate
          - Sand-centered
          - Massive
          - Clustered
          - Free
          - Drusy
        - Oomoldic
          - Skeletal
          - Abundant
          - Scattered
      - Coarse
        - Unmodified
        - Lacy
        - Drusy
        - Dolomoldic
          - Skeletal
          - Abundant
          - Scattered
        - Dolomorphic
        - Oolitic
          - Concentric
          - Radiate
          - Sand-centered
          - Massive
          - Clustered
          - Free
          - Drusy
        - Oomoldic
          - Skeletal
          - Abundant
          - Scattered
  - Anhedral
    - Loose
    - Aggregated
    - Granulated
      - Fine
        - Unmodified
        - Lacy
        - Drusy
        - Dolomoldic
          - Skeletal
          - Abundant
          - Scattered
        - Dolomorphic
        - Oolitic
          - Concentric
          - Radiate
          - Sand-centered
          - Massive
          - Clustered
          - Free
          - Drusy
        - Oomoldic
          - Skeletal
          - Abundant
          - Scattered
      - Coarse
        - Unmodified
        - Lacy
        - Drusy
        - Dolomoldic
          - Skeletal
          - Abundant
          - Scattered
        - Dolomorphic

- Oolitic
  - Massive
  - Clustered
  - Free
  - Drusy
- Oomoldic
  - Skeletal
  - Abundant
  - Scattered
- Anhedral
  - Loose
  - Aggregated
  - Granulated

- Coarse
  - Unmodified
  - Lacy
  - Drusy
  - Dolomoldic
    - Skeletal
    - Abundant
    - Scattered
  - Dolomorphic
  - Oolitic
    - Concentric
    - Radiate
    - Sand-centered
    - Massive
    - Clustered
    - Free
    - Drusy
  - Oomoldic
    - Skeletal
    - Abundant
    - Scattered

- CHERT
  - SMOOTH
    - Chalcedonic
    - Ordinary
    - Porcelaneous
  - GRANULAR
    - Fine
    - Coarse
  - CHALKY

- Porcelaneous
- GRANULAR
  - Coars

CHART OF INSOLUBLE RESIDUES
by
INSOLUBLE RESIDUE CONFERENCE
Midland, Texas
June, 1946

CHART OF INSOLUBLE RESIDUES
by
INSOLUBLE RESIDUE CONFERENCE
Midland, Texas
June, 1946

- Unmodified
- Lacy
- Drusy
- Dolomoldic — Skeletal, Abundant, Scattered
- Dolomorphic
- Oolitic — Concentric, Radiate, Sand-centered, Massive, Clustered, Free, Drusy, Pseudoolitic
- Oomoldic — Skeletal, Abundant, Scattered
- Granulated
- Sandy
- Silty
- Banded
- Spicular
- Fossiliferous

- Unmodified
- Lacy
- Drusy
- Dolomoldic — Skeletal, Abundant, Scattered
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- Granulated
- Sandy
- Silty
- Banded
- Spicular
- Fossiliferous

- Unmodified
- Lacy
- Drusy
- Dolomoldic — Skeletal, Abundant, Scattered
- Dolomorphic
- Oolitic — Concentric, Radiate, Sand-centered, Massive, Clustered

ARGILLACEOUS MATERIAL

- CLAY
  - Sponge-like
    - Unmodified
    - Lacy
    - Dolomoldic — Skeletal, Abundant, Scattered
    - Dolomorphic
    - Oolitic — Concentric, Radiate, Sand-centered, Massive
    - Oomoldic — Skeletal, Abundant, Scattered
    - Sandy
    - Silty
    - Fossiliferous
  - Flaky
    - Unmodified
    - Lacy
    - Dolomoldic — Skeletal, Abundant, Scattered
    - Dolomorphic
    - Oolitic — Concentric, Radiate, Sand-centered, Massive
    - Oomoldic — Skeletal, Abundant, Scattered
    - Sandy
    - Silty
    - Fossiliferous
  - Massive — Sandy, Silty, Fossiliferous
- SHALE
  - Smooth — Flaky, Waxy, Laminated
  - Dolomoldic — Skeletal, Abundant, Scattered
  - Oolitic — Concentric, Radiate, Sand-centered, Massive
  - Oomoldic — Skeletal, Abundant, Scattered
  - Sandy
  - Silty
  - Fossiliferous
  - Glauconitic
  - Pyritic
  - Micaceous
  - Other Minerals

- Spicular
- Fossiliferous

- Unmodified
- Lacy
- Drusy
- Dolomoldic — Skeletal, Abundant, Scattered
- Dolomorphic
- Oolitic — Concentric, Radiate, Sand-centered, Massive, Clustered, Free, Drusy, Pseudoolitic
- Granulated
- Sandy
- Silty
- Banded
- Spicular
- Fossiliferous

ne

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- Lacy
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- Oomoldic — Skeletal, Abundant, Scattered
- Granulated
- Sandy
- Silty
- Banded
- Spicular
- Fossiliferous

arse

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- Oomoldic — Skeletal, Abundant, Scattered
- Granulated
- Sandy

- SHALE
  - Oolitic — Radiate, Sand-centered, Massive
  - Oomoldic — Skeletal, Abundant, Scattered
  - Sandy
  - Silty
  - Fossiliferous
  - Glauconitic
  - Pyritic
  - Micaceous
  - Other Minerals

ARENACEOUS MATERIAL

- SILT
  - Loose — Quartzose, Glauconitic, Pyritic, Micaceous, Other Minerals
  - Aggregates
    - Poorly consolidated — Sandy, Quartzose, Glauconitic, Pyritic, Micaceous, Other minerals
    - Well consolidated
      - Unmodified
      - Dolomoldic — Abundant, Scattered
      - Oolitic — Concentric, Radiate, Sand-centered, Massive
      - Oomoldic — Abundant, Scattered
      - Sandy
      - Fossiliferous
      - Glauconitic
      - Pyritic
      - Micaceous
      - Other minerals
- SAND
  - Loose
    - Rounded — Frosted, Polished, Etched
    - Subrounded — Frosted, Polished, Etched
    - Angular
    - Regenerated
  - Aggregates
    - Poorly consolidated
      - Rounded — Frosted, Polished, Etched
      - Subrounded — Frosted, Polished, Etched
      - Angular
      - Regenerated
    - Well consolidated
      - Rounded — Frosted, Polished, Etched
      - Subrounded — Frosted, Polished

- Free
- Drusy
- Pseudoolitic
- Oomoldic — Skeletal, Abundant, Scattered
- Granulated
- Sandy
- Silty
- Banded
- Spicular
- Fossiliferous

Coarse

- Unmodified
- Lacy
- Drusy
- Dolomoldic — Skeletal, Abundant, Scattered
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- Banded
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- Fossiliferous

ARENACEOUS MATERIAL

- Oomoldic — Abundant, Scattered
- Sandy
- Fossiliferous
- Glauconitic
- Pyritic
- Micaceous
- Other minerals

- SAND
  - Loose
    - Rounded — Frosted, Polished, Etched
    - Subrounded — Frosted, Polished, Etched
    - Angular
    - Regenerated
  - Aggregates
    - Poorly consolidated
      - Rounded — Frosted, Polished, Etched
      - Subrounded — Frosted, Polished, Etched
      - Angular
      - Regenerated
    - Well consolidated
      - Rounded — Frosted, Polished, Etched
      - Subrounded — Frosted, Polished, Etched
      - Angular
      - Regenerated

- ANHYDRITE
  - MASSIVE
    - Fine granular
    - Coarse aggregates — Subhedral, Anhedral
  - FIBROUS
  - SUBHEDRAL
  - ANHEDRAL
- GYPSUM
  - MASSIVE
  - FIBROUS
  - SELENITIC

ACCESSORY: Sulphur, pyrite, marcasite, sphalerite, millerite, magnetite, hematite, limonite, feldspar, muscovite, biotite, chlorite, glauconite, barite, celestite, other insoluble minerals; fossils, pellets, beekite.

description. Many possible types of residues are given a place in the outline, though their existence has not been confirmed. It is believed that the outline will contain a descriptive term for all anticipated types of residues, but it is recognized that additions or alterations may later be necessary.

As far as possible, each descriptive term is intended to be clear-cut and restrictive; and, within limits, a residue fragment may be pigeon-holed. It should be emphasized, however, that types of residues grade into other types and therefore some specific fragments may not be easily placed, and different persons may place a fragment under a different but related type.

The description of crystalline, quartzose, drusy, or granular siliceous material is greatly facilitated by separating quartz from chert and eliminating the terms vitreous and crystalline from the nomenclature. All clear, vitreous, and crystalline quartz is classified as euhedral, subhedral, or anhedral. Drusy quartz is specifically restricted to subhedral. The term "granular" is substituted for the term crystalline because the crystalline appearance of a fragment is generally due to the reflection of light from grains or granules. If a fragment is actually composed of recognizable quartz crystals it would be classified as some form of quartz thus preventing any confusion with a chert residue fragment. Much chert and other residues referred to as crystalline should be called "drusy."

"Smooth" is a term applied to one of the three major types of chert. It is subdivided into chalcedonic, ordinary, and porcelaneous. "Chalcedonic" includes all vitreous, milky, translucent, and transparent chert. Other varieties of chert are described in the outline. Any of these cherts may be oölitic, dolomoldic, sandy, or otherwise modified as shown in the outline.

Terminology for Insoluble Residues

I. QUARTZ: Ordinarily clear colorless quartz, not detrital
- A. EUHEDRAL: Doubly terminated crystals; unattached
- B. SUBHEDRAL: Crystal forms partially developed
  1. Loose: Individual fragments separated from former attachment
  2. Drusy: Clusters or aggregates of crystals; generally incrustations
  3. Granulated: Grains or granules partially cemented or loosely aggregated; saccharoidal; grade from angular to drusy; fine to coarse; particle rarely larger than 0.5 mm. in diameter
     - a. Fine:
       - (1) Unmodified: Residue uniform with no modifying characteristics
       - (2) Lacy: Residues with irregular openings in which the constituent material comprises less than 25% of the volume of the fragment
       - (3) Drusy: Incrusted with subhedral quartz
       - (4) Dolomoldic: Containing dolomolds. (Dolomolds are rhombohedral openings in an insoluble residue. Term *dolomoldic* is used for same feature that McQueen originally called *dolocastic*.[16] Term *dolocastic* is given by Cloud, Barnes, and Bridge[17] to a feature not a dolomold and entirely different from original application by McQueen. Their definition of *dolocastic* should not be used because of confusion with original application by McQueen and widespread former usage of McQueen's term *dolocastic* in literature. See dolomorphic below.)
         - (a) Skeletal with dolomolds: Residues with rhombohedral openings in which constituent material comprises less than 25% of volume of fragment. Openings vary from microscopic to megascopic

[16] H. S. McQueen, *op. cit.* (1931), p. 9.

[17] P. E. Cloud, V. E. Barnes, and Josiah Bridge, "Stratigraphy of the Ellenburger Group in Central Texas—A Progress Report," *Univ. Texas Pub. 4301* (1945), p. 135.

(b) Abundant dolomolds: Residues with rhombohedral openings with constituent material comprising from 25% to 75% of the volume of fragment. Openings vary from microscopic to megascopic

(c) Scattered dolomolds: Residues having rhombohedral openings in which constituent material comprises more than 75% of volume of fragment. Openings vary from microscopic to megascopic

(5) Dolomorphic: Used for describing insoluble residues where there has been replacement or alteration of dolomite or calcite by insoluble mineral which assumes crystal form of the soluble mineral, thus filling a dolomoldic cavity. Term dolomorphic is same as *dolocastic* used by Cloud, Barnes, and Bridge. Dolomorphic describes conditions but does not put new meaning to obsolete word *dolocastic*

(6) Oölitic: Containing oöliths.[18] (Oöliths as applied to insoluble residues are spheroidal bodies with nucleus or central mass enclosed by one or more surrounding layers of same or different material. Oöliths found as residues may be of any color. They may be composed of hematite, limonite, pyrite, bauxite, silica, clay, and barite. Any of these may have replaced dolomite, calcite, aragonite, siderite, or phosphate. Many oöliths differ in color and in composition from enclosing matrix. Oöliths grade from small to large but generally are less than 1.0 mm. in diameter. Those larger than 2.0 mm. in diameter are called *pisoliths*

(a) Concentric: Peripheral layers around small undetermined nucleus

(b) Radiate: Fibers radiating from small undetermined or large identifiable nucleus; may have several peripheral layers

(c) Sand-centered: Nucleus a quartz sand grain

(d) Massive: Interior of granular, smooth or chalk-textured material comprising nearly entire mass of spheroid

(e) Clustered: Attached oöliths without solid matrix

(f) Free: Unattached oölith

(g) Drusy: Oölith covered with subhedral quartz; may be free, clustered, or aggregated by matrix

(7) Oömoldic: Residue containing oömolds which are spheroidal openings representing former presence of oöliths

(a) Skeletal with oömolds: Constituent material less than 25% of volume of fragment. Openings vary from microscopic to megascopic

(b) Abundant oömolds: Constituent material 25% to 75% of volume of fragment Openings vary from microscopic to megascopic

(c) Scattered oömolds: Constituent material comprising more than 75% of volume of fragment. Openings vary from microscopic to megascopic

b. Coarse:

(1) Unmodified

(2) Lacy

(3) Drusy

(4) Dolomoldic

(a) Skeletal

(b) Abundant

(c) Scattered

(5) Dolomorphic

(6) Oölitic

(a) Concentric

(b) Radiate

(c) Sand-centered

(d) Massive

(e) Clustered

(f) Free

(g) Drusy

(7) Oömoldic

(a) Skeletal

(b) Abundant

(c) Scattered

C. ANHEDRAL: No crystal form developed. (This includes quartz formerly referred to as vitreous and drusy.)

1. Loose:

[18] Ronald K. DeFord and W. A. Waldschmidt, "Oölite and Oölith," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30 (1946), pp. 1587–88.

2. Aggregated: Well aggregated grains of any size, does not include detrital sand
3. Granulated:
    a. Fine:
        (1) Unmodified
        (2) Lacy
        (3) Drusy
        (4) Dolomoldic
            (a) Skeletal
            (b) Abundant
            (c) Scattered
        (5) Dolomorphic
        (6) Oölitic
            (a) Concentric
            (b) Radiate
            (c) Sand-centered
            (d) Massive
            (e) Clustered
            (f) Free
            (d) Drusy
        (7) Oömoldic
            (a) Skeletal
            (b) Abundant
            (c) Scattered
    b. Coarse:
        (1) Unmodified
        (2) Lacy
        (3) Drusy
        (4) Dolomoldic
            (a) Skeletal
            (b) Abundant
            (c) Scattered
        (5) Dolomorphic
        (6) Oölitic
            (a) Concentric
            (b) Radiate
            (c) Sand-centered
            (d) Massive
            (e) Clustered
            (f) Free
            (g) Drusy
        (7) Oömoldic
            (a) Skeletal
            (b) Abundant
            (c) Scattered

II. CHERT: Cryptocrystalline varieties of quartz regardless of color; composed mainly of petrographically microscopic fibers of chalcedony and / or quartz particles whose outlines range from easily resolvable to non-resolvable with binocular microscope at magnifications ordinarily used by petroleum geologists. Particles rarely exceed 0.5 mm. in diameter
  A. SMOOTH: Conchoidal to even fracture; surface devoid of roughness; may be botryoidal; homogeneous; no distinctive structure, crystallinity or granularity
    1. Chalcedonic: Transparent to translucent; smoky; milky; waxy to greasy; may be any color, generally buff or blue-gray; may be finely mottled. (This includes chert formerly referred to as transparent or translucent chert.)
        a. Unmodified
        b. Lacy
        c. Drusy
        d. Dolomoldic
            (1) Skeletal
            (2) Abundant
            (3) Scattered
        e. Dolomorphic
        f. Oölitic
            (1) Concentric
            (2) Radiate

(3) Sand-centered
(4) Massive
(5) Clustered
(6) Free
(7) Drusy
(8) Pseudoölitic: Rounded pellets with no peripheral layers or sharp distinction between pellets and matrix. Pseudoölith may be an oölith with peripheral layer absorbed or replaced

g. Oömoldic
(1) Skeletal
(2) Abundant
(3) Scattered

h. Granulated
i. Sandy: Containing sand grains
j. Silty: Containing silt grains
k. Banded: Varied color bands
l. Spicular: Containing sponge spicules. (Free spicules have been noted.)
m. Fossiliferous: Containing fossils or fossil fragments or cavities

2. Ordinary: Even fracture surface; all colors, chiefly white, gray, or brown; may be mottled; approaches opaque; generally homogeneous, but may have slight evidence of granularity or crystallinity
a. Unmodified
b. Lacy
c. Drusy
d. Dolomoldic
(1) Skeletal
(2) Abundant
(3) Scattered
e. Dolomorphic
f. Oölitic
(1) Concentric
(2) Radiate
(3) Sand-centered
(4) Massive
(5) Clustered
(6) Free
(7) Drusy
(8) Pseudoölitic
g. Oömoldic
(1) Skeletal
(2) Abundant
(3) Scattered
h. Granulated
i. Sandy
j. Silty
k. Banded
l. Spicular
m. Fossiliferous

3. Porcelaneous: Smooth fracture surface; hard, opaque to subtranslucent; typically china-white resembling china-ware or glazed porcelain; grades to chalky
a. Unmodified
b. Lacy
c. Drusy
d. Dolomoldic
(1) Skeletal
(2) Abundant
(3) Scattered
e. Dolomorphic
f. Oölitic
(1) Concentric
(2) Radiate
(3) Sand-centered
(4) Massive
(5) Clustered

(6) Free
(7) Drusy
(8) Pseudoölitic
g. Oömoldic
(1) Skeletal
(2) Abundant
(3) Scattered
h. Granulated
i. Sandy
j. Silty
k. Banded
l. Spicular
m. Fossiliferous

B. GRANULAR: Compact; homogeneous; composed of distinguishable relatively uniform-sized grains, granules, or druses; uneven or rough fracture surface; dull to glimmering luster; hard to soft; may appear saccharoidal. (This is type of residue formerly referred to as crystalline chert.)
1. Fine: Individual grains difficult to differentiate
a. Unmodified
b. Lacy
c. Drusy
d. Dolomoldic
(1) Skeletal
(2) Abundant
(3) Scattered
e. Dolomorphic
f. Oölitic
(1) Concentric
(2) Radiate
(3) Sand-centered
(4) Massive
(5) Clustered
(6) Free
(7) Drusy
(8) Pseudoölitic
g. Oömoldic
(1) Skeletal
(2) Abundant
(3) Scattered
h. Granulated
i. Sandy
j. Silty
k. Banded
l. Spicular
m. Fossiliferous
2. Coarse: Individual grains easily recognizable (Grains rarely reach 0.5 mm. in diameter.)
a. Unmodified
b. Lacy
c. Drusy
d. Dolomoldic
(1) Skeletal
(2) Abundant
(3) Scattered
e. Dolomorphic
f. Oölitic
(1) Concentric
(2) Radiate
(3) Sand-centered
(4) Massive
(5) Clustered
(6) Free
(7) Drusy
(8) Pseudoölitic

g. Oömoldic
(1) Skeletal
(2) Abundant
(c) Scattered
h. Granulated
i. Sandy
j. Silty
k. Banded
l. Spicular
m. Fossiliferous

C. CHALKY: Uneven or rough fracture surface; commonly dull or earthy in many cases; soft to hard; may be finely porous; essentially uniform composition; resembles chalk or tripolite. (Formerly referred to as *dead* or *cotton* chert. This includes dull unglazed porcelaneous material which grades into glazed porcelaneous material described under porcelaneous smooth chert. See II—A—3.)
1. Unmodified
2. Lacy
3. Drusy
4. Dolomoldic
a. Skeletal
b. Abundant
c. Scattered
5. Dolomorphic
6. Oölitic
a. Concentric
b. Radiate
c. Sand-centered
d. Massive
e. Clustered
f. Free
g. Drusy
h. Pseudoölitic
7. Oömoldic
a. Skeletal
b. Abundant
c. Scattered
8. Sandy
9. Silty
10. Banded
11. Spicular
12. Fossiliferous

III. ARGILLACEOUS MATERIAL
A. CLAY: Fine material of clay size
1. Sponge-like: Porous, earthy, fragile
a. Unmodified
b. Lacy
c. Dolomoldic
(1) Skeletal
(2) Abundant
(3) Scattered
d. Dolomorphic
e. Oölitic
(1) Concentric
(2) Radiate
(3) Sand-centered
(4) Massive
f. Oömoldic
(1) Skeletal
(2) Abundant
(3) Scattered
g. Sandy
h. Silty
i. Fossiliferous

2. Flaky:
   a. Unmodified
   b. Lacy
   c. Dolomoldic
      (1) Skeletal
      (2) Abundant
      (3) Scattered
   d. Dolomorphic
   e. Oölitic
      (1) Concentric
      (2) Radiate
      (3) Sand-centered
      (4) Massive
   f. Oömoldic
      (1) Skeletal
      (2) Abundant
      (3) Scattered
   g. Sandy
   h. Silty
   i. Fossiliferous
3. Massive:
   a. Sandy
   b. Silty
   c. Fossiliferous

B. SHALE: All colors, many kinds of texture, hard to soft, may be porous, waxy, or granular
1. Smooth:
   a. Flaky
   b. Waxy
   c. Laminated
2. Dolomoldic
   a. Skeletal
   b. Abundant
   c. Scattered
3. Oölitic
   a. Concentric
   b. Radiate
   c. Sand-centered
   d. Massive
4. Oömoldic
   a. Skeletal
   b. Abundant
   c. Scattered
5. Sandy
6. Silty
7. Fossiliferous
8. Glauconitic
9. Pyritic
10. Micaceous
11. Other minerals

IV. ARENACEOUS MATERIAL

A. SILT: Grains of silt size, chiefly quartz, but may be composed entirely or partially of other minerals
1. Loose grains
   a. Quartzose
   b. Glauconitic
   c. Pyritic
   d. Micaceous
   e. Other minerals
2. Aggregates: All colors, many kinds of textures, hard to soft, may be porous
   a. Poorly consolidated
      (1) Quartzose
      (2) Sandy
      (3) Glauconitic

(4) Pyritic
(5) Micaceous
(6) Other minerals
b. Well consolidated (chiefly siltstone)
(1) Unmodified
(2) Dolomodic
(a) Abundant
(b) Scattered
(3) Oölitic
(a) Concentric
(b) Radiate
(c) Sand-centered
(d) Massive
(4) Oömoldic
(a) Abundant
(b) Scattered
(5) Sandy
(6) Fossiliferous
(7) Glauconitic
(8) Pyritic
(9) Micaceous
(10) Other minerals
B. SAND: Grains of sand size, chiefly quartz, but may be composed entirely or partially of other minerals
1. Loose grains
a. Rounded: Essentially spheroidal or ellipsoidal, coarse to fine
(1) Frosted
(2) Polished
(3) Etched
b. Subrounded: Polygonal shape but with well rounded edges and corners
(1) Frosted
(2) Polished
(3) Etched
c. Angular: Irregular plane or curved surfaces with sharp edges and corners
d. Regenerated: Secondary regrowth of crystal faces oriented with original axis of grain. Perfection of recrystallization controlled by adjacent particles
2. Aggregates: Generally white, brown, buff, red or green, depending on cement or constituents, hard to soft, may be porous
a. Poorly consolidated
(1) Rounded
(a) Frosted
(b) Polished
(c) Etched
(2) Subrounded
(a) Frosted
(b) Polished
(c) Etched
(3) Angular
(4) Regenerated
b. Well consolidated: (Chiefly sandstone) Grains described as below
(1) Rounded
(a) Frosted
(b) Polished
(c) Etched
(2) Subrounded
(a) Frosted
(b) Polished
(c) Etched
(3) Angular
(4) Regenerated
V. ANHYDRITE
A. MASSIVE
1. Fine granular: (Alabaster-like)

2. Coarse aggregates:
   a. Subhedral
   b. Anhedral

B. FIBROUS
C. SUBHEDRAL
D. ANHEDRAL

VI. GYPSUM
A. MASSIVE: Includes alabaster
B. FIBROUS: (Satin spar)
C. SELENITIC: Cleavage plates or crystals

VII. ACCESSORY
A. SULPHUR
B. PYRITE
C. MARCASITE
D. SPHALERITE
E. MAGNETITE
F. HEMATITE
G. LIMONITE
H. FELDSPAR
I. MICA
   1. Muscovite
   2. Biotite

J. CHLORITE
K. GLAUCONITE
L. BARITE
M. CELESTITE
N. OTHER INSOLUBLE MINERALS
O. FOSSILS
P. PELLETS
Q. BEEKITE: Botryoidal, subspherical, or discoid accretions of opaque silica replacing organic matter, generally white

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RELATION OF CLAY MINERALOGY TO ORIGIN AND RECOVERY OF PETROLEUM[1]

RALPH E. GRIM[2]
Urbana, Illinois

ABSTRACT

The clay-mineral concept of the nature of clays and shales is briefly discussed in its relation to problems of the origin and recovery of oil and gas.

The character of the clay minerals that make up a sediment is to a considerable degree the result of diagenetic changes in the environment of accumulation. Diagenetic changes suggested by present available data are considered.

The relation of various clay minerals to organic material in argillaceous sediments is discussed in the light of evidence which suggests that certain clay minerals under certain conditions are the key factor in the transition of organic matter to petroleum.

The properties of clay minerals are considered as a basis for analyzing the effect of water with dissolved electrolytes, moving through a sand, on any clay in the sand. The characteristics of the clay minerals are believed to be significant factors in the recovery of oil.

Other significant effects of the properties of the various clay minerals are discussed.

INTRODUCTION

Extensive researches in recent years have shown that clay materials, including shales, are composed essentially of extremely small crystalline particles of members of any one or more of a few groups of minerals known as the "clay minerals" (4).[3] In addition to the clay minerals, variable but usually small amounts of quartz, calcite, limonitic material, organic material, feldspar, and a host of other minerals may be present as extremely minor constituents, or as prominent constituents in occasional clays. Amorphous material has been proved in only a very few of the great number of soils, clays and shales that have been studied, and it is clear that it is not a significant factor in clays generally.

The factors which are necessary to characterize completely a clay material and also those that control its properties may be listed as follows.

1. Clay-mineral composition—the relative abundance of the clay-mineral components and their particle-size distribution.
2. Non-clay-mineral composition—the relative abundance of each mineral and the size-grade distribution of its particles.
3. Electrolyte content—the kind and amount of the exchangeable ions and any water-soluble salts.
4. Organic content—the amount, kind, and relation to other components.
5. Miscellaneous textural characteristics such as shape of quartz grains, degree of parallel orientation of the clay-mineral particles, and silicification.

The clay minerals are the essential constituents of clay materials and they are the most important single factor in determining the properties of these materials. There are three general kinds of clay minerals: (1) minerals in which the individual ultimate units have a sheet or flake shape; (2) minerals in which the ultimate

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[2] Principal geologist, Illinois State Geological Survey.

[3] Numbered references are listed at the end of this article. Reference 4 contains an extensive bibliography on the structure, properties, occurrence, and methods of study of the clay minerals.

units are fibrous or lath-shaped; and (3) amorphous minerals. The sheet or flake-shaped clay minerals are by far the most abundant, and the best known. The amorphous components have been proved in only a few clays. The more common and well known clay minerals are listed in Table I.

Researches in many fields (mineralogy, geology, chemistry, engineering, agriculture) have led to fairly adequate methods of identifying the clay minerals and have provided considerable information on their structure, composition, properties, and occurrence. The analytical methods and clay mineralogical data are covered in a voluminous literature (4) which is not reviewed herein. Many of these clay mineralogical data are very important in problems of the origin, recovery, and refining of petroleum. Of particular significance is the work that has

TABLE I

CLAY MINERALS

	Composition
1. Kaolinite group	
a. Equidimensional flake-shaped units	
Kaolinite	$(OH)_8Al_4Si_4O_{10}$
Anauxite	
b. Lath-shaped units	
Halloysite minerals	$\begin{cases}(OH)_8Al_4Si_4O_{10} \\ (OH)_8Al_4Si_4O_{10} \cdot 4H_2O\end{cases}$
2. Montmorillonite group	
a. Equidimensional flake-shaped units	
Montmorillonite	$(OH)_4(Al_4 \cdot Fe_4 \cdot Mg_4)Si_8O_{20} \cdot nH_2O$
b. Lath- or needle-shaped units	
Nontronite	
Hectorite	$(OH)_4(Mg \cdot Li)_6Si_8O_{20}$
3. Illite group	$(OH)_4K_y(Al_4 \cdot Fe_4 \cdot Mg_4)(Si_{8-y} \cdot Al_y)O_{20}$
Insufficient data to subdivide	
4. Miscellaneous fiber-shaped units	
Attapulgite	$(OH_2)_4(OH)_2Mg_5Si_8O_{20} \cdot 4H_2O$
Sepiolite-like	$(OH)_4Mg_6Si_8O_{20} \cdot ?H_2O$
5. Amorphous	

been done on the structure of the clay minerals, which has greatly increased our understanding of the fundamental causes of their properties and the factors that determine their origin. It is proposed, herein, to analyze some of these clay-mineral data in relation to such problems, and to indicate researches on the subject that appear desirable and promising.

CLAY MINERALS AS CLUES TO ENVIRONMENT OF ACCUMULATION OF ARGILLACEOUS SEDIMENTS

It has long been the idea of many geologists that clay is an end-product of weathering and a material of great stability. As a generality this is simply not true. On the contrary, clay minerals are dynamic things, and great and important changes in structure, composition, and properties may result when a change takes place in the parameters of the environment in which the clay mineral is

found. The material is an end-product only so long as there is no environmental change. A clay-mineral composition that would be in equilibrium with one environment would probably not be in equilibrium with another environment. For example, kaolinite is a product of weathering in some areas, but it is certainly not the weathering product in all areas.

Clay minerals may change quickly, commonly in a matter of years, in response to changes in environment. Investigators of soils have proved the dynamic character of the clay minerals beyond reasonable doubt, and only one bit of evidence need be mentioned. Careful detailed studies have shown that illite develops from other clay minerals in a matter of years as a consequence of the addition of potash fertilizer in some soils and under certain conditions (12).

Since clay minerals are dynamic things, one would suspect that they might undergo important diagenetic changes. Few specific data on actual diagenetic changes in argillaceous sediments are available, but what evidence (2, 5) there is points to the conclusion that the clay-mineral composition of sediments is largely a result of conditions in the environment of accumulation, such as alkalinity of water, character of dissolved salts, temperature, rate of accumulation, and kind and amount of organic material. Furthermore, the evidence indicates that the diagenetic changes take place rapidly—a major part probably takes place quickly after the sediment arrives in the environment of accumulation. The character of the source material is important, for one would suspect on the basis of the structure of the clay minerals that kaolinite would be relatively resistant to change, whereas montmorillonite and illite would be less resistant, and perhaps the fibrous clay minerals would be least resistant of all. It is interesting that montmorillonite is a common product of present-day weathering under certain conditions, but rare in ancient marine sediments. It is suggestive that illite is the dominant clay-mineral component of many marine argillaceous sediments. Illite is the clay mineral in many, perhaps most, marine shales—its origin is probably due largely to diagenetic processes. In general the changes should be greater in a marine or brackish-water environment than in one with fresh water.

Considerable work has been done on the synthesis (9) of the clay minerals in the laboratory, and soil investigators (8) are studying the kind of clay minerals that are developing under certain weathering conditions. As yet the results do not permit any broad generalizations, but they do show that the presence of certain chemical elements in certain amounts greatly aids (or is required at times for) formation of certain clay minerals. Thus, potash is necessary for illite to form, and magnesium seems to be essential for at least some montmorillonite.

As the character of the clay mineral is a consequence of the environment, it should be possible to interpret the environment from clay-mineral data. This does not mean that simple determinations of the presence of illite or montmorillonite-type mineral will be adequate. Rather it is going to be necessary to determine the kind of montmorillonite, kind of illite, *et cetera*, and by kind is meant the replacements within the lattice and the character of the exchangeable bases. Replace-

ments are possible within the lattice of some clay minerals, such as iron and magnesium for aluminum in the illites and montmorillonite, and aluminum for silica in the illites and possibly some montmorillonites. Such substitutions almost certainly reflect environmental conditions, but as yet almost nothing is known regarding the conditions controlling possible replacements. This is a very fruitful field for research. It is known that replacements may cause very great changes in properties, even to altering the habit of the clay mineral. Thus, as iron replaces aluminum in the montmorillonite lattice, the mineral changes from flake-shaped to lath-shaped, at least under certain conditions. There are probably other factors that lead to an elongate rather than equidimensional unit, but they are not known.

Researches on Recent sediments are much needed. Considerable data on the origin of clay minerals are coming from soil studies and synthesis experiments, and the compositions of many ancient sediments are fairly well known. Investigations of Recent sediments to fill in the gap are necessary to provide information on diagenetic processes and to permit an evaluation of the sedimentary history of ancient sediments. Such researches must be complete in that the detailed character of *all* the clay minerals in the sediments must be determined. A very small amount of one clay-mineral component may be the key to the evaluation of sedimentary history. Further, the clays must be studied in relation to the factors of the environment, that is, character of water, electrolyte contents, bacteria, and organic content.

CLAY MINERALS AND ORGANIC COMPOUNDS

Organic material may be present in argillaceous sediments in two ways: first, as discrete particles mechanically mixed with the clay minerals and the non-clay minerals, and second, as molecules adsorbed (3) on the clay-mineral surfaces, mostly the basal-plane cleavage surfaces.

The unit cell of montmorillonite is a sheet-like structure whose flat surfaces are planes of oxygen atoms arranged in a definite pattern (7) (Fig. 1). Of very great significance is the point that the configuration and dimensions of this pattern of oxygen atoms is such that there is a very close possible fit (1) with the configuration and dimensions of the structural arrangement of the carbon atoms in certain organic compounds. Certain clay minerals have a catalytic effect on certain organic compounds, and it has been reasoned that this catalytic effect is a consequence of the approximate fit of the structures of the clay mineral and the organic compounds.

Adsorption of organic compounds is probably due to a combination of structure of the surface, cleanness of the surface, and replacements within the lattice. With regard to cleanness of surface, it appears that the presence of certain cations, and possibly anions adsorbed on the clay-mineral unit surface, will prevent the adsorption of organic materials. Exceedingly small amounts of such ions may have very large detrimental effects. Conversely, there is some slight reason to believe

that certain other ions, again in very small amounts, may have a large beneficial effect. Replacements within the lattice appear to be of great importance—the effect on organic material of one variety of montmorillonite is much greater than that of another. In fact only certain kinds of montmorillonite seem to have the catalytic property to an important degree.

Obviously, from the foregoing, the relation of clay minerals to organic compounds varies with the kind and variety of clay mineral. For example, kaolinite

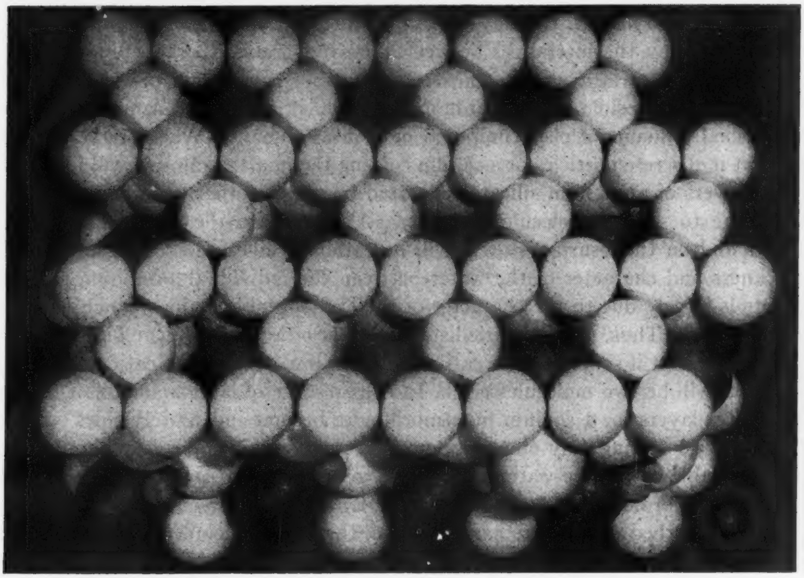

FIG. 1.—Structure of montmorillonite showing, particularly, hexagonal configuration of oxygen atoms (white balls) of basal plane surfaces of unit cells. Black balls represent hydroxyls and small gray balls represent aluminum. Silica atoms are at center of tetrahedron of four oxygens and can not be seen.

would have this property to a slight degree whereas certain varieties of montmorillonite have it to a very high degree.

The significant point is that the clay minerals could well be an important instrument whereby buried organic material is changed to oil. This is an exceedingly fertile field for research, and many specific problems could be mentioned, for example: differences in the catalytic effect of the varieties of the montmorillonite clay minerals; amounts and kind of any organic material adsorbed in Recent argillaceous sediments. The fruits of successful researches in such directions are so obvious that they do not require elaboration; however, one point may be mentioned. There is some reason to believe that if a clay mineral acted as a catalyst in

the transformation of organic material to petroleum, a residue of carbon would be left behind on the catalytic surface. If that were so, we might have a potential clue to determine whether or not a clay mineral has so acted in the past.

CLAY MINERALOGY AND RECOVERY OF PETROLEUM

Clay minerals are found in sands and sandstones as discrete particles mixed with the quartz grains and as a film plastered around the quartz grains, or only as a film around the grains. In the movement of a fluid through a sand, the objective would be not to disturb the clay-mineral particles in any way that would cause them to occupy the interstices between the sand grains, thereby plugging the sand.

In order to consider the matter in more detail, let us assume a sand containing some small amount of clay composed of montmorillonite. Whether the clay is present in discrete particles or as a film coating the quartz grains, it will be made up of layers of aluminum silicate separated from each other by layers of water from one to several molecules thick (7). Also between the aluminum silicate layers and on their surfaces there will be cations which are exchangeable. The thickness and character of the water between the individual aluminum silicate sheets is largely due to the character of the exchangeable cations which happen to be present. Thus, in an air-dried state, a layer of water a single molecule thick may be present if sodium is the cation, whereas if calcium is the cation the layer of water will be two molecules thick. In the presence of large amounts of water, the water layers for a sodium montmorillonite become indefinitely thick with a thickness depending only on the amount of water present. When calcium is the exchangeable cation the water layer tends to be restricted to a few molecules in thickness regardless of the amount of water available.

The adsorbed cations are exchangeable, that is, if calcium is present on the montmorillonite in the sand, and water containing sodium in certain concentrations moves through the sand, a base-exchange reaction will result in which sodium goes on the montmorillonite in exchange for calcium which leaves the montmorillonite and is carried away by the water. The important thing and the point to be made here is that as a consequence of such an exchange reaction, the relation between the aluminum silicate and the water layer would no longer be stable and a new one would tend to develop. The result of the development of a new equilibrium would probably be the separation of the individual flakes, a splitting of discrete clay particles, and an unplastering of the quartz grains. The net result would be the liberation of minute clay-mineral particles which would plug the sand.

It follows from the foregoing discussion that the presence of sodium in water moving through a sand containing a calcium montmorillonite clay would probably tend to cause clogging, whereas, if the montmorillonite carried sodium as the exchangeable base, there might be little clogging. Similarly for a calcium montmorillonite clay, calcium in the water would probably have little clogging

effect. In water-flooding operations it would seem desirable to know the character of any clay component in the sand and the nature of its exchangeable base.

The situation would be much less critical if some clay mineral other than montmorillonite made up the clay in a sand. Kaolinite for example has low base-exchange capacity and the aluminum silicate layers are held together tightly without intervening water layers (4). As a consequence it has less tendency to break into very small units because of variations in character of the cation. The illite clay minerals are intermediate between kaolinite and montmorillonite in their tendency to break up because of cation variations.

In natural sands one is apt to find a mixture of clay minerals, such as a small amount of montmorillonite interlaminated with illite. The interlamination is apt to be on an exceedingly minute scale, that is unit cells of montmorillonite and illite interlaminated. In such mixtures the montmorillonite provides potential planes of weakness along which the whole particle could break down. Under such conditions a relatively small component of montmorillonite in a clay would cause the whole clay to be sensitive to variations in the character of the cation. In studying such problems it is not adequate to determine only the abundant clay-mineral components—the determination must be complete including those present in only very small amounts.

It is well known that the dispersibility of kaolinite and illite clays in water varies somewhat with the kind and amount of electrolyte. This is a matter of the charge on the clay-mineral particle and not exactly the same phenomenon previously discussed. However, the over-all conclusion would still be the same, namely, that the character of the electrolyte content of the clay and water should be compatible—at least the electrolyte content of the clay should be known.

Another factor in the relation of clay mineralogy to the recovery of petroleum is that some organic compounds can be adsorbed on the surface of the clay minerals—probably to a very limited extent for kaolinite and to a very great extent for montmorillonite, because of the structure of the surface and the potentially great amount of surface per unit weight. Some hydrocarbons in oil sands are probably adsorbed on the surface of the clay-mineral units. Any attempt to sweep off such hydrocarbons would probably also accomplish a separation of the clay-mineral flakes and a clogging of the pores.

An important point in the cation adsorption and base-exchange properties of clay minerals is that there is a high degree of selectivity which varies among the different clay minerals for different cations (11). Not all of the ions are exchanged with equal ease—thus it is easier to exchange calcium for sodium on a clay mineral than it is to replace the calcium held on a clay by sodium. Further the relative ease of the exchangeability of two cations is not the same for all the clay minerals. This selectivity probably should be the point of departure for researches to devise methods and materials to better control the dispersibility of the clay component of sands. It can be pointed out that very small amounts of certain materials, for example, the complex phosphates, greatly influence the

development of the adsorbed water, at least in certain clay minerals. There is a possibility that certain chemicals may be found which will inhibit the development of adsorbed water which causes dispersion of the clay particles.

Researches are in progress in the laboratory of the Illinois State Geological Survey on the character of the clay mineral in the producing formations in Illinois. The character of the clay mineral varies in different sands, and although it is too early to state conclusions, the results appear to have promising value in planning water-flooding operations.

CLAY MINERALOGY AND DRILLING MUDS

The relation of clay mineralogy to drilling muds is a big subject and perhaps beyond the field of interest to many in this group. It is proposed here to make only a few points which illustrate certain attributes of the clay minerals that are demonstrated in drilling muds and that are of general importance to the problems at hand.

A characteristic of the montmorillonite clay minerals is that water enters between the unit cells which are about 9.5Å thick, and that layers of water develop between the units, thereby separating them (7). In montmorillonites of certain kinds and when sodium is the exchangeable base, water layers of great thickness may be formed, in fact the thickness is dependent on the amount of water, and the individual units may be substantially completely separated from each other. In such montmorillonites, and probably in other clay minerals as well, the water layers between the units are made up of oriented water molecules (12), that is, there is a definite pattern or structure to the water—it is crystalline. The orientation of the water molecules begins at the surface of the montmorillonite unit because of the structure of the oxygen atoms in the surface layer, and continues outward from the surface through large distances in such montmorillonite. A certain amount of time, usually measured in minutes, is required for the orientation to be completed. The orientation is not very rigid and can be destroyed by agitation. The orientation accompanied by the development of rigidity develops again after agitation ceases. This is the property of thixotropy so important in drilling muds.

In other kinds of montmorillonite and in those with some exchangeable bases other than sodium, water seems to enter between the individual layers only to a very limited extent, so that even though the water itself is composed of oriented water molecules, the property of thixotropy is substantially absent.

Of considerable general importance is the fact that small amounts of certain cations and anions exert a large influence on the perfection of the orientation of the water, the thickness to which it develops, and the rate of the development of the orientation. Certain complex phosphates, for example, in exceedingly small amounts may greatly alter the properties of a drilling mud. This illustrates a very significant generality regarding clays, namely, that certain materials in very small amounts very greatly influence the properties of certain clays. The explanation

for the effect of the phosphates probably rests in the approximate structural fit of the phosphate in the water lattice thereby distorting but not destroying entirely the oriented water.

Clay mineralogy is important also in the refining of petroleum—in the preparation of decolorizing agents and catalysts. This matter is probably beyond the field of petroleum geology. However, it should not be overlooked in any broad research investigation of clay mineralogy in the petroleum industry, not only because of its immediate economic importance to refining, but also because of the light it might throw on the possible catalytic action of clay minerals on the organic material in sediments.

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GEOLOGICAL NOTES

PALEOZOIC-MESOZOIC SECTION IN SOUTHEASTERN TURKEY[1]

CEVAT E. TASMAN[2]
Ankara, Turkey

The sacred mount Cudi (Joody), the rival of Mt. Ararat in lore as the landing place of Noah's ark, has geologically a better claim for that distinction. Fringing its steep-dipping southern slopes is a thick section of sand and siltstones, and conglomerates extending part way to Habur Su on the boundary with Iraq. The undoubted fluviatile origin of the greater part of these sediments, together with the proximity of the Tigris and its substantial tributary, lends a scientific background to the Flood and the grounding of the historic vessel that the bold igneous mass emerging from the flat plains of Igdir, in case of Mt. Ararat, totally lacks.

The Joody-Sheyhabat Mountain in southeastern Turkey, 40–50 kilometers east of Cizre (Jezire) along the Tigris, exposes a thick section predominantly composed of limestones extending from the Upper Paleozoic well beyond the Middle Cretaceous. This lithologic unit, comparable with the Tamasopo limestone in Mexico, has been subdivided since it first received attention in 1929 and 1930 by Shirley Mason[3] and the writer.[4] It is known now that the quartzitic member at the base may be correlated with the Devonian quartzitic section in the western Taurus, as indicated by M. Blumenthal,[5] and the quartzitic sandstones of the Bakhtiari Mountains which are referred to the Devonian by G. M. Lees.[6] The fossils collected in 1930 gave a Carboniferous age to the part of the section observed and this age determination has been substantiated and extended by finding Permian and Triassic fossils higher in the section. Later, Maxson differentiated from the Lower Triassic a formation which encloses Upper Triassic and Jurassic. This upper unit will undoubtedly be subdivided further with increased opportunities of observation in the future. It will be seen that the Joody section is a far more comprehensive unit than the Tamasopo of Mexico which spans from the Austin chalk down to the Kimmeridge of the Upper Jurassic. The following table gives the names adopted for the various members of the section.

Mardin limestone	Middle Cretaceous
Tanin Tanin formation	Jurassic, Upper Triassic
Goyan formation	Lower Triassic
Harbol limestone	Permo-Carboniferous and Upper Devonian

[1] Manuscript received, March 29, 1947.

[2] M.T.A. Petrol. Grubu.

[3] Shirley Mason, "Geology of Prospective Oil Territory in Republic of Turkey," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), p. 687.

[4] Djevad Eyoub, "Petroleum Possibilities of Turkey," *ibid.*, Vol. 15 (1931), p. 629.

[5] Maurice Blumenthal, "Un Apercu de la Geologic du Taurus," *Meteae Mem. 6*, Ser. B.

[6] G. M. Lees, "The Geology of the Oilfield Belt of Iran and Iraq," *Science of Petroleum*, Vol. 1, p. 140.

At Harbol, a section of about 600 meters of limestone is exposed which is referred to the Upper Paleozoic. At the base it is brown, quartzitic, and contains argillaceous intercalations. Upward in the column, the limestone becomes dark gray with conchoidal fracture. It contains *Productus semireticulatus*, *Productus gigantus*, and *Fusilinella* sp.? Still higher in the section the limestones become thin-bedded and contain *Mizzia velebiltina*, *Productus horridus*, and *Derbiya*

FIG. 1

armenica. The lower part of the Harbol limestone is Carboniferous and the upper 250–300 meters Permian.

The Harbol limestone passes without a break into the Triassic. According to Lees, the Permo-Carboniferous in Iran also passes into the Triassic without an unconformity. The section above is 250 meters thick and, with the exception of 20 meters of chocolate-colored shales and the minor quantities of greenish sandstones, is composed entirely of yellowish marly limestone. It appears above the Paleozoic Harbol limestone not only in the Joody-Sheyhabat region but also around Goyan on the northeast. The name of Goyan is used for the section immediately and conformably overlying the Permian. The following fossils have been identified in the Goyan formation: *Pseudomontis claii* and *Myophoria ovata*, giving it a Lower Triassic or Werfenian age. This limestone is yellowish in color, emits a fetid odor, and is thin-bedded, giving a banded appearance.

In the Tanin Tanin Mountains, and on the east, another thick limestone series is exposed overlying the Lower Triassic Goyan. This series is darker in color and largely dolomitic. It shares the characteristic fetid odor with the Goyan series. The thickness of the Tanin Tanin formation is 600–700 meters. The fossils, which are rare, suggest a Ladinian facies of the Alpine Triassic according to Arni. *Halobia halorica* has been identified from Maxson's collection in Tanin Tanin. The limestone section continues upward into the Jurassic.

Near Mardin the top 250–300 meters of the massive gray limestone is exposed. To this the name of Mardin limestone is given. It contains *Hippurites*, *Radiolites*, *Caprina*, and *Inoceramus*. Though the presence of *Hippurites gosaviensis* and *H. cornuvaccinum* suggests Senonian, an isolated ammonite and microfaunal evidence points to a Turonian age. Above the Mardin limestone sedimentation conditions change. After a transitional flaggy limestone and shale series a thick marl and shale section occurs which is partly Upper Cretaceous and partly Paleocene, the passage from one to the other being recognized only by micropaleontologic methods.

AID TO PLANE-TABLE MAPPING[1]

HOBART E. STOCKING[2]
Stillwater, Oklahoma

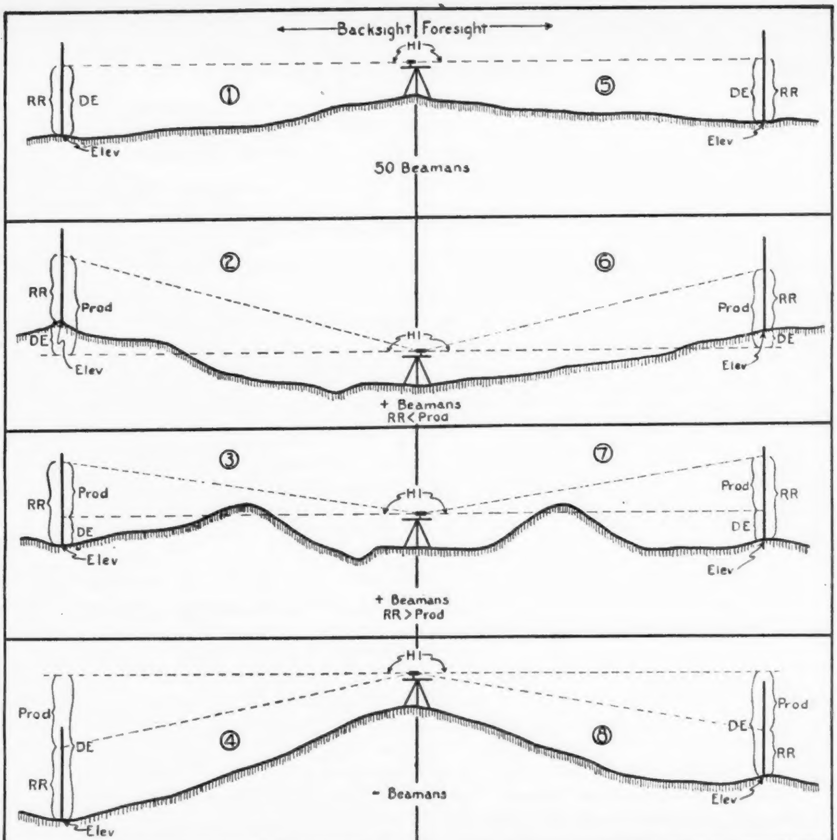
Between the logical development of theory and the straight path of acquired facility in the use of a telescopic alidade there is a devious way through a number of operations, each complicated by its relation to backsight or foresight, plus angles, minus angles, or no angle. For an amateur, quick passage through the operations is facilitated by glance at the chart of Figure 1, attached directly to the plane-table sheet or in the notebook.

The Beaman stadia arc method for obtaining vertical angles with the telescopic alidade is the procedure most readily comprehended by students who lack previous training in engineering. This procedure for determining elevations not on the line of traverse (side shots), supplemented by either the "step" or angle method for turning points in the line of traverse, utilizes the flexibility of the alidade to obtain speed where first-degree accuracy is not required (in side shots) and accuracy, within the limits of the machine, where it is essential.

The chart includes the possible shots and a logical sequence of operations which carry the topographer from station to station. With experience the method of note-keeping can be shortened but for a beginner it is well that there be a record of every operation so that when the traverse fails to close within the limits of accuracy the error can be recognized as a deviation to be avoided in the future.

[1] Manuscript received, April 2, 1947.

[2] Department of geology, Oklahoma A. and M. College.



Operations performed in order of lettering	A Direction	B Rod Intercept	C Rod Reading	D Beamans	E Product	F D. E.	G H. I.	H Elevation
Backsight	Record direction on sheet when fiducial edge bisects known point on sheet & vertical wire falls on Rod	RI X100=D scale distance when calculations are complete RI X100=D	Rod Reading is height above ground at which middle wire cuts Rod when whole number of Beamans are opposite Beaman Index	① No Beamans	No product	RR = DE	Elev+DE=HI	
				② + Beamans	RI X B=Prod	Prod-RR=DE	Elev-DE=HI	
				③ + Beamans		RR-Prod=DE	Elev+DE=HI	
				④ - Beamans		Prod+RR=DE	Elev+DE=HI	
Foresight				⑤ No Beamans	No product	RR=DE		HI-DE=Elev.
				⑥ + Beamans	RI X B=Prod	Prod-RR=DE		HI+DE=Elev.
				⑦ + Beamans		RR-Prod=DE		HI-DE=Elev.
				⑧ - Beamans		Prod+RR=DE		HI-DE=Elev.

RI = *Rod Intercept, the distance between upper and lower stadia wires as measured on the Rod*
D= *Distance from known point to point to be located*
Product = *Difference in elevation between HI and point where center wire cuts Rod*
DE= *Difference in elevation between HI and base of Rod*
HI= *Height of instrument above datum*
Backsight = *a sight from an unknown location to a known point*
Foresight = *a sight from a known point to an unknown location*

FIG. 1

Use of the chart presumes a comprehension of the theory of operation of a telescopic alidade and an understanding of its mechanical principles. The chart may serve as a basis for an explanation of both.

OPERATIONS FOR DIRECTION, DISTANCE AND ELEVATION

A. With the fiducial edge, bisect known point on plane table sheet and at same time have vertical wire in the telescope fall on the rod.

   1. Draw along fiducial edge a line extending from known point on sheet toward the rod. This is the direction line.

B. Read Rod Intercept: with tangent screw place either top or bottom horizontal wire on a whole-foot division on the rod and read the distance on the rod between the top and bottom horizontal wires.

   This distance, read in feet and tenths of a foot is the Rod Intercept. R.I.$\times$100 =Distance. (For this operation the vertical wire need not fall on the rod.)

C. Determine Rod Reading:

   1. With tangent screw, level telescope striding level.
   2. With Beaman level-screw, set Beaman index *exactly* opposite 50 Beamans or zero, depending on the type of instrument. When the striding level is leveled and Beaman index set opposite 50 Beamans, the Beaman level should be in level position *if* the two levels are in adjustment. If they are in adjustment then in subsequent sights from the same station it is sufficient to use only the Beaman level in determining the Rod Reading and the number of Beamans. If they are not in agreement then they should be adjusted or else the striding level may be leveled for each shot.
   3. With the tangent screw, place the center horizontal wire *anywhere* on the rod preferably near its center. Then, with the same screw, place the nearest Beaman interval mark *exactly* opposite the Beaman index. Check to see that center wire is still somewhere on the rod.
   4. Read the position of the center stadia wire on the rod. This is the Rod Reading. Wave rodman off the point but do not touch alidade until next step is completed.

D. Read Beaman Intervals from the arc.

   Plus Beamans are those greater than 50; minus Beamans are those less than 50.

E, F, G, H. Calculate and record Product, D.E., and H.I., or Elevation.

I. Scale Distance along direction line, placing estimated portion of scale opposite known point.

   Example: Scale reads in 10-foot intervals; Distance is 655 feet. Place 55′ opposite known point and by needle-prick opposite 600′ division of scale record location of new station.

Remember that accuracy has priority over speed: two stations accurately determined cover more ground than ten carelessly located, since the latter must be redetermined.

THRUST FAULT ZONES IN VENTURA BASIN, LOS ANGELES AND VENTURA COUNTIES, CALIFORNIA[1]

J. W. SHELLER[2] AND M. N. BIEN[3]
Bakersfield, California

The Red Mountain, San Cayetano, Oakridge, and Santa Susana faults are four of the major thrusts of the Ventura basin (Fig. 1). Although they are widely separated areally and vary considerably in details, these faults have a common characteristic in that a wedge of Modelo[4] shale typically occurs between an older

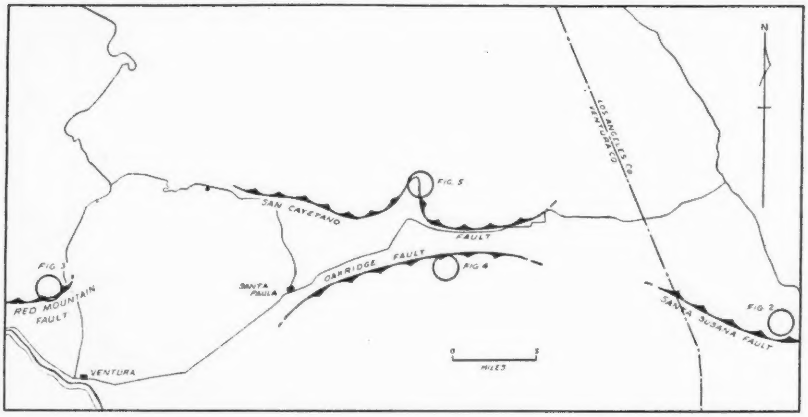


FIG. 1.—Location map of Ventura basin faults.

formation above and a younger formation below. The shale is always highly fractured, and is often referred to as a fault zone when encountered in a well. Following are descriptions of four easily recognized occurrences.

Santa Susana fault (Fig. 2).—The Tide Water Associated Oil Company's Porter well, No. 12 in the Aliso Canyon oil field, penetrated 400 feet of fractured Modelo brown shale of middle Miocene age, after going through the massive Topanga[5] sandstone of lower Miocene age. Immediately below this zone the Pico[6] sandstones and siltstones of upper Pliocene age were encountered. It is

[1] Read before the Association at Los Angeles, March 26, 1947. Manuscript received, April 28, 1947.

[2] Richfield Oil Corporation.

[3] Geological Survey of China.

[4] F. S. Hudson and E. K. Craig, "Geologic Age of the Modelo Formation, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 5 (May, 1929), p. 509. No. 11 (December, 1929), p. 1519.

[5] W. S. W. Kew, "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California," *U. S. Geol. Survey Bull. 753* (1924), pp. 48–51.

[6] W. S. W. Kew, *op. cit.*, pp. 71–80.

apparent that the upper and lower contacts of the Modelo shale are fault planes along which stratigraphic displacement has occurred.

Data from adjacent wells indicate that the fault planes converge downward and seem to diverge upward.

Red Mountain fault (Fig. 3).—The Continental Oil Company's Casitas well, No. 2 drilled on Red Mountain in Ventura County, passed from hard Eocene sandstone into Modelo shale of Miocene age. About 200 feet of shale was penetrated when the bit encountered Repetto siltstone of lower Pliocene age. Approxi-

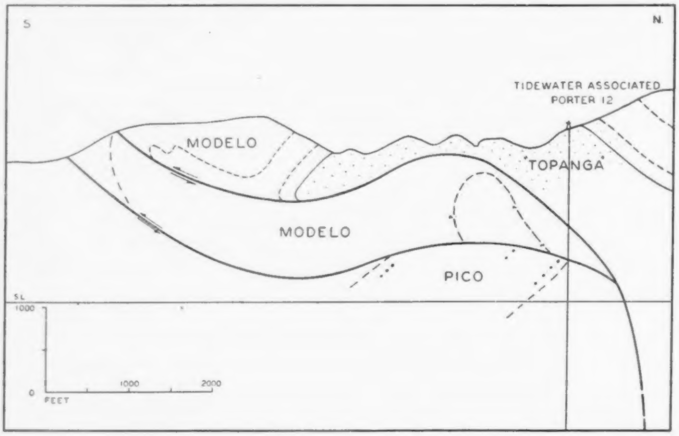


Fig. 2.—Idealized cross section through Santa Susana fault at Aliso Canyon field.

mately 1,400 feet below the Modelo-Repetto contact, beds of the Pico formation (upper to middle Pliocene) were found. All of these contacts are in inverse stratigraphic sequence due to reverse faulting. Thus, three distinct fault planes are present with a thin wedge of Modelo shale lying between the first two.

In outcrops a mile south of the Casitas well only two large faults are apparent. A thin exposure of lower Miocene Rincon shale with Oligocene (?) Sespe[7] red sandstone overlying it, in an overturned attitude, is thrust over Modelo shale which, in turn, has overridden Pico beds.

Oakridge fault (Fig. 4).—A deep well in the Shiells Canyon area penetrated approximately 900 feet of fractured Modelo shale lying between Sespe beds above and upper Pico beds below. Two distinct fault planes are indicated.

Northward and updip on the fault planes other wells have found the Modelo wedge considerably thinner, varying from almost nothing to 200 feet. The two fault planes, then, are converging updip toward the outcrop. This is in contrast to the Santa Susana and Red Mountain fault zones.

[7] W. S. W. Kew, *op. cit.*, pp. 36–37.

San Cayetano fault (Fig. 5).—An outcrop on the east bank of Sespe Creek, near the mouth of the canyon, shows a distinct fault zone composed of highly fractured Rincon and Modelo shales of lower and middle Miocene age, respectively, in fault contact with each other. This crushed zone lies between the up-

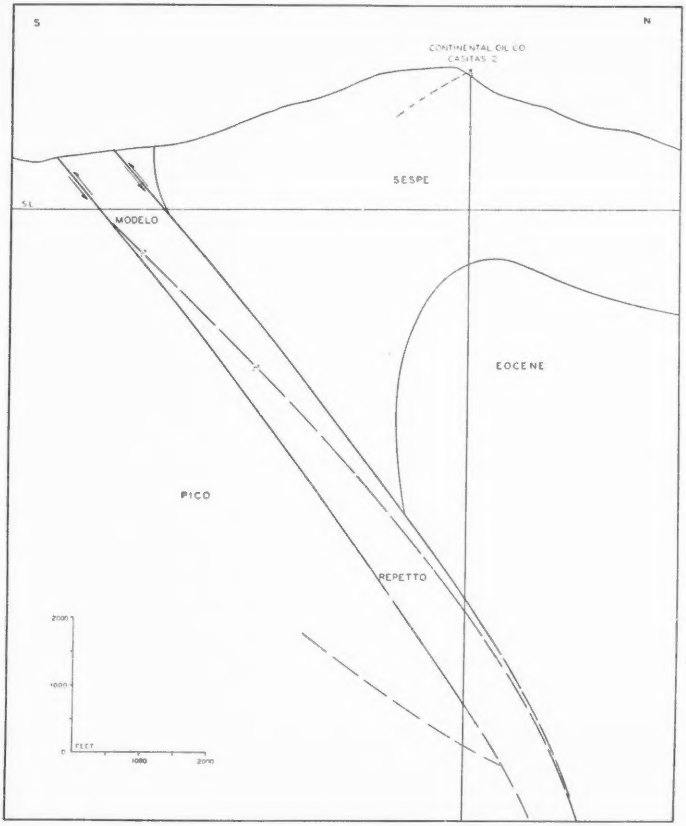


FIG. 3.—Idealized cross section through Red Mountain fault.

thrust Sespe sandstone of Oligocene (?) age and the steeply tilted Saugus conglomerate of Pleistocene age. The three fault contacts are clearly shown by narrow zones of fault gouge and breccia.

In the vicinity of Boulder Creek, about ½ mile along the fault trace, a sliver of brown shale seems to be lying by fault contact between Eocene sandstone and Pico mudstone.

Pleito fault.—A case similar to those cited has been reported in the vicinity of Pleito Creek in the San Emigdio Hills, Kern County, California. Here, Maricopa clay shale (Miocene) has been overridden by Vaqueros sandstone (lower

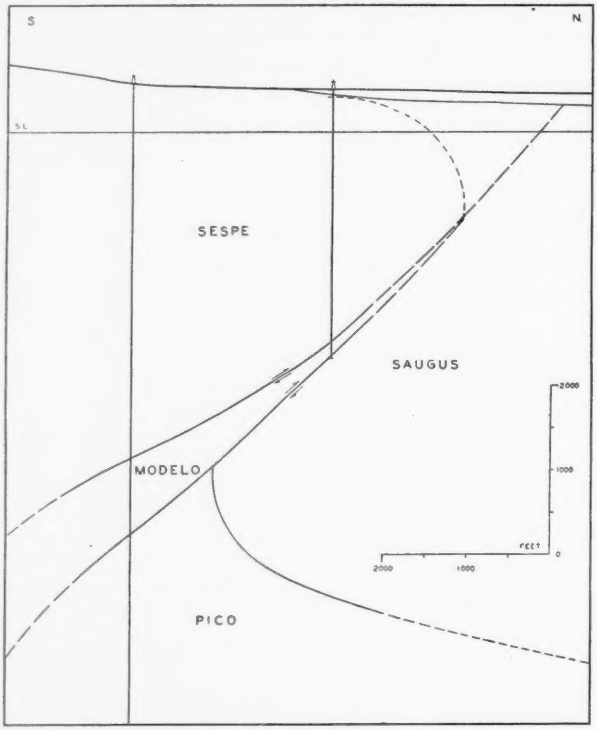


FIG. 4.—Idealized cross section through Oakridge fault, west of Shiells Canyon field.

Miocene) and has, in turn, overridden Tulare (?) Pleistocene beds along a large thrust fault.[8]

Conclusions.—The similarity in fault zones of the faults described suggests that there is some causal factor common to each case. It may be postulated that the lithologic character of the Modelo shale is that factor.

One possible hypothesis explaining the fault zone phenomenon is as follows.

The lower fault plane developed within the Modelo shale as a result of overturned folding and may be viewed as the initial plane along which movement

[8] H. W. Hoots, "Geology and Oil Resources along the Southern Border of San Joaquin Valley, California," *U. S. Geol. Survey Bull. 812-D.*

took place. During development of the fault the transmission of stress became impossible, due to the increasing structural weakness of the overriding shale mass in the forepart of the upper block as it emerged from depth, with a consequent decrease in overburden. This relative weakness allowed more competent rocks from the overriding block to glide out over the shale mass, thus resulting in a second fault plane. The overridden shale acted as an efficient lubricating material for the fault plane.

Theoretically, if the foregoing postulation is true, a lenticular mass of shale

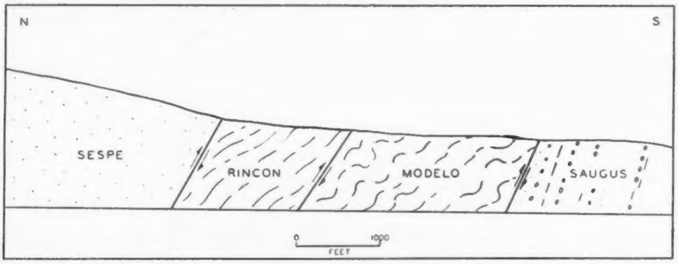


FIG. 5.—Outcrop section in Sespe Creek showing San Cayetano fault.

(in cross section) should result from convergence of the two fault planes at depth and again near the surface of the ground. Convergence at depth is suggested in the Santa Susana fault and the Red Mountain fault. Convergence near the surface is clearly demonstrated by the Oakridge fault. On no one fault has the double convergence been demonstrated.

Due to the insufficiency of available data, the nature of the shale wedge along the strike of these faults can not be determined. Furthermore, the faults themselves undoubtedly change character along strike.

RAPID OXIDATION OF GLAUCONITE IN GLAUCONITIC SAND[1]

WATSON H. MONROE[2]
Washington, D. C.

During the course of several years of field work the writer has noticed that at least three substances, all considered glauconite petrographically, have different weathering characteristics. Samples of glauconite from the greensand deposits of New Jersey retain their characteristic green color, and individual grains retain their hardness after several years in storage. The glauconite from the Upper

[1] Manuscript received, May 1, 1947. Published by permission of the director of the United States Geological Survey.

[2] United States Geological Survey.

Cretaceous Eutaw formation of the Gulf Coastal Plain is much softer and upon exposure to weathering oxidizes rapidly to limonite. A third type common in the Upper Cretaceous Eoline and McShan formations consists of fine pale green grains that upon weathering oxidize to pale amber grains of a clay-like material.

That the Eutaw-type glauconite oxidizes very rapidly was observed by the writer and C. A. Carlson, geologist of the Mobile Army Engineer Office, while examining auger samples collected less than a year before from test holes along the route of the proposed Tennessee-Tombigbee waterway in Mississippi. In some of the samples the glauconite had oxidized to ferruginous sand in which limonitic crusts had formed, similar to those common in ferruginous formations of the Coastal Plain.

Most of the samples taken by the Engineer Corps at dam sites were cores, but in unconsolidated materials the holes were bored with a post-hole auger and the samples were collected with a piston-type bailer. These samples were placed while still wet in glass Mason jars which were then sealed with the usual rubber rings between the top of the jar and the metal-porcelain tops. In most of the jars examined the ring had afforded an air-tight seal but in a few of the jars sand grains had lodged between the rubber ring and the screw cap allowing access to the outside air, and in these jars the water had evaporated an inch or more below the top of the sand since the jars were sealed.

This condition was especially noticeable in samples from auger-hole No. 353, (depth, 99.5 feet) in Sec. 13, T. 4 S., R. 9 E., 0.3 mile northwest of Holcut, Tishomingo County, Mississippi, which was drilled in August, 1938, into the Eutaw formation. In this hole below a depth of 20 feet (3 feet below the water table) the fresh samples consisted of dark green glauconitic sand containing scattered thin flakes of black shaly clay, but in those jars in which the seal was not air-tight the upper part of the sand was dry and the color had changed from deep green to rusty brown, the glauconite having been oxidized to impure limonite (Fig. 1). Within the limonitic portion of each sample were three paper-thin layers of limonite similar in miniature to the limonitic crusts found at intervals throughout the Eutaw and other glauconitic formations. In some of the jars these plates were nearly horizontal but in others they had a highly irregular surface. The sand below the water surface in the jars was dark green, just as in those jars whose seals had remained air-tight.

The oxidation of the glauconite in the samples from auger hole No. 363 had taken place between August 13, 1938, when the jars were sealed, and July 18, 1939, when the samples were examined—less than a year. The writer interprets the formation of the limonite layers as due to concentration of iron oxide at temporary stands of the water level within the jars. The level of the water was probably controlled by variations in rate of evaporation corresponding with variations in relative humidity and temperature.

Experiments under controlled conditions that might determine the rate of oxidation of glauconite and the mode of origin of limonitic crusts would yield

quantitative data. One experiment, for instance, could involve the placing of highly glauconitic sand in open-mouthed jars in which the water level could be maintained at a constant position to see whether the limonite forms at the water table. Other experiments might include slight raises and reductions of the water level from time to time, and observations of the effects on the sand of varying

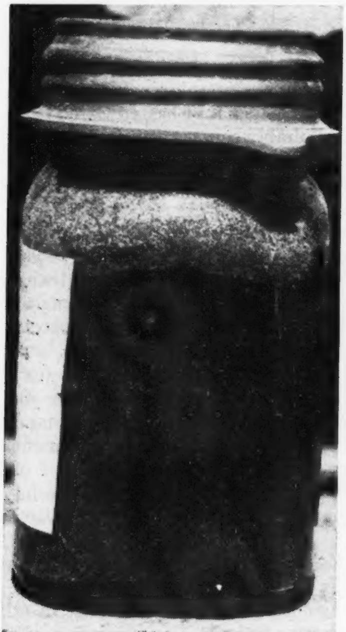


FIG. 1.—Jar of glauconitic sand in which upper part has oxidized to limonitic sand.

temperature and humidity with constant and varying water levels. In connection with these experiments chemical analyses of the unweathered and weathered glauconite and the water should be made to determine what happens to the potash of the unweathered glauconite. If such experiments are made, the writer suggests that unweathered samples of the Eutaw formation of Mississippi be obtained, for he doubts that the glauconite of New Jersey, for example, will react in the same way.

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DISCUSSION

RELATIONSHIP OF CRUDE OILS AND STRATIGRAPHY[1]

BELA HUBBARD[2]
Tucson, Arizona

The latest report of the research committee of the Tulsa Geological Society on the "Relationship of Crude Oils and Stratigraphy in Parts of Oklahoma and Kansas"[3] is, to this writer, the most interesting paper that has appeared in the *Bulletin* in many years. The committee[4] have been admirably conservative in setting forth their conclusions based on the data. This may be just as well, because the permanent value of the work lies in the data, which will doubtless be supplemented in the future by further studies of the same and other crude oils.

It should be generally agreed that the committee's work has pretty well demonstrated that in at least some instances, and in certain types of pools, the oil has migrated very little. And this alone would justify all the work that has been done. As for demonstrating the practicability of correlating crude oils by their chemical characteristics and tying them in to the stratigraphy, the work has been very successful, and a continuation of these studies is surely worth while.

There is another aspect of the subject which, perhaps for good reasons, has not been emphasized in the paper. This is the possible bearing these data may have on the origin of petroleum. The writer attended for several years the committee meetings of American Petroleum Institute Research Project 43 ("Transformation of Organic Matter into Petroleum"), and very naturally read the paper with this phase of the subject in mind. The following comments and speculations are offered with the hope they will suggest additional reasons for a continuation of the work of the research committee of the Tulsa Geological Society.

1. In all the committee's curves showing correlation index *versus* cut numbers for the different classes of crude oils, the higher the cut, the higher the percentage of naphthenic and the lower the percentage of paraffinic constituents. In other words, as we go from the lower to the higher molecular weights, the proportion of naphthenic compounds increases and the proportion of paraffinic compounds decreases. To a lesser extent, there is an increase also in the aromatics as we go into the higher boiling points and the higher molecular weights. It would be interesting to know if this trend toward predominance of naphthenes and aromatics continues into the residuum.

2. Of the higher molecular-weight hydrocarbons and hydrocarbon-like compounds (solids at ordinary temperatures) which are produced by the metabolism of present-day living plants (including the microflora) by far the greater proportion are naphthenes and aromatics and their structurally related non-hydrocarbons, and many complicated, unsaturated ring compounds such as chlorophyl and the derived porphyrins, and carotenes. Only a small percentage of the hydrocarbon solids are paraffinic, and only a few known plants contain major proportions of paraffines among their metabolized waxes. For

[1] Manuscript received, April 10, 1947.

[2] Standard Oil Company (New Jersey).

[3] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31, No. 1 (January, 1947), pp. 92–148.

[4] L. M. Neumann, chairman, N. W. Bass, R. L. Ginter, S. F. Mauney, T. F. Newman, Charles Ryniker, and H. M. Smith.

example, tobacco wax is 100 per cent normal paraffines; the Candelilla weed of Mexico contains wax which is about 50 per cent paraffine (probably isoparaffines).

3. In Parker Trask's work on bottom sediments (assumed to be potential "embryonic" petroleum source sediments) practically no evidence of petroleum was found; but organic matter in small percentages was recovered. This organic matter occurred apparently as solids and liquids, though presumably chiefly as solids at normal temperatures. Much of this material appeared to be waxes, resins, *et cetera*. Even these small percentages of organic solids would be adequate to account for all our petroleum, if converted to hydrocarbons of lower molecular weights.

4. It is probable that in recent botton sediments, such as those studied by Trask, only the heavy, high-molecular-weight hydrocarbon-like compounds would be retained by the sediment; in other words, only the waxes, resins, *et cetera*, with perhaps some liquids and gases adsorbed on the inorganic mineral grains or dissolved in the solid waxy mixtures. Most of the gases and liquids would escape, during and soon after sedimentation, into the overlying water, where they would be dispersed, oxidized, and otherwise lost to the sediment. Hence, the organic source compounds from which crude oils are eventually derived, commence their sedimentary existence as solids (at normal superficial temperatures). Since these hydrocarbon-like solids are for the most part unsaturated and structurally very complex ring and branch-chain compounds, geologically young crude oils should be relatively high in such compounds and low in the lighter ends and in the structurally simple compounds such as the normal paraffines. In support of this idea is the evidence of porphyrins, which appear to occur most abundantly in the geologically younger crude oils. Such evidence as there is suggests that during the aging (genesis) of petroleum in the sediments, these highly complex organic compounds are reduced, decarboxylated, or otherwise broken down into simpler, more hydrocarbon-like compounds of lower molecular weights and lower melting points, which are liquids or gases at normal earth temperatures.

5. The work of A.P.I. Research Project 43 has indicated several ways in which high-molecular-weight hydrocarbons and hydrocarbon-like compounds may be broken down into lighter ends. Among these are:

(a) Action of alpha-particle bombardment from radioactive sediments. For example, a long-chain fatty acid may be decarboxylated to a paraffine of slightly lower molecular weight and lower melting point.

(b) The action of lipoclastic bacteria. Crude oils subjected to the action of certain bacteria have shown a decrease in specific gravity and viscosity.

6. In general, waxes and other crude-oil constituents of high molecular weight and complex chemical structure are probably either original members of the organic complex of solid and semi-solid petroleum source material, or else they are slight modifications of such original organic compounds. For example, the fatty acid $CH_3(CH_2)_{24}COOH$, known as hexacosanoic acid, and which is a constituent of many plant waxes, would by decarboxylation (loss of CO_2) become the normal paraffine $C_{25}H_{52}$ (pentacosane), a common constituent of petroleum waxes.

In some instances waxes and other high-molecular-weight compounds in sedimentary rocks may have been dissolved and picked up by a migrating oil. But whether they be "charter members" of the source material or subsequent acquisitions, the various destructive processes aforementioned may reduce most of them to the lighter ends which form the bulk of the liquid and gas components of crude oils.

If we accept, for the moment, the general accuracy of the statements made in the foregoing six numbered paragraphs, then the following generalizations seem reasonable.

1. *Other factors being equal*, the older the crude oil the lower will be the average molecular weight of its component compounds, and in general, the higher the A.P.I. gravity of the crude.

2. *Other factors being equal*, the older the crude oil the higher the proportion of paraffines, which are structurally the simplest of all the hydrocarbons, and chemically the most stable.

3. The aromatic compounds, with their double bonds, are less stable than the cycloparaffines (naphthenes), and therefore, *other factors being equal*, the older the crude oil, the lower the proportion of aromatics.

4. When we find in different sand lenses of a formation, such as the Bartlesville, oils of different types, some aromatic, some naphthenic, some paraffinic, then we may reason that in such cases the *other factors* were *not equal*. Since the environments for all these neighboring sand lenses were presumably similar; since the geologic history has been practically identical throughout the area of occurrence, the implication is that the organic source materials differed among the various localities where and when the sand lenses were deposited. In one locality the parent material was highly aromatic, in another highly naphthenic, *et cetera*. Slight differences in the inorganic mineral constituents of the sand or of the adjacent shale may have influenced the end result somewhat. For example, certain metals are known to be bacterial inhibitors, and a small but critical increase in the percentage of nickel (for example) in one sand body may have inhibited growth of certain bacteria with an appetite for aromatic compounds; result, the original aromatic compounds in this pool survived more successfully than the same compounds in a nearby pool in which the sediments contained less than the critical concentration of nickel. On the whole, however, the chemical character of the organic source material was probably the most important factor. According to L. Murray Neumann, there are known instances of apparent vertical migration where the oil is chemically the same in several horizons of different inorganic mineral composition.

Regardless of whether or not the foregoing speculations are reasonable, the writer believes that far more attention should be given to the waxes, asphaltenes, and other solid constituents of petroleums. These are the constituents which are usually left with the bottom settlings in tank bottoms, and which petroleum chemists usually dismiss rather summarily under the catch-all designation "residuum." These much avoided and little known hydrocarbons may be proved to be the most significant of all, because they may be the sole survivors of the original source complex, and in their separation and identification we may have a preferred means of "finger-printing" crude oils.

In this connection, and referring now to petroleum waxes and not to asphaltic materials, the writer has determined from microscopic studies that much of the petroleum wax commonly designated as paraffine is actually the ceresin of commerce; and no one knows just what ceresin is. The writer has noted at least two types of ceresin wax, both very different from normal paraffine waxes. Some of this "ceresin," the writer believes, is almost certainly a homologous series of isoparaffines, and some is probably a series of solid cycloparaffines (naphthenes). A comprehensive x-ray study of these waxes is urgently needed, and a research project should be undertaken with the definite objective of learning the true chemical structures of all these petroleum waxes.

Some time ago, the writer, through the kindness of L. Murray Neumann, received wax samples from a number of Oklahoma and Kansas crudes. Microscopic studies showed these to be almost entirely ceresins with only minor percentages of normal paraffines present in samples from some of the crudes. These Oklahoma-Kansas waxes are very different from those of the Pennsylvania crude oils, which are almost wholly normal paraffine waxes. Even among the normal paraffine waxes from different crude oils there are notable differences which are evident from microscopic studies of the crystals. The Pennsylvania normal paraffines have characteristics which differentiate them from the normal paraffine waxes of crude oils from other parts of the world. Crude ozocerites from Utah and those from Borislaw (Poland) may be recognized by differences in crystalline char-

acters, though both are composed chiefly of ceresins with minor percentages of higher members of the normal paraffine series. Since these and many more differences in petroleum waxes can be determined from microscopic observations, the writer is convinced that a promising field of research is indicated, in which the assistance of chemists, x-ray specialists, and others is sorely needed.

The work of the research committee of the Tulsa Geological Society should go on, and it should be augmented to include studies of the petroleum waxes, asphalts, and whatever other compounds may be present in the residuum of crude-oil samples.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 8 (AUGUST, 1947), PP. 1516-1523

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

THE PEAT DEPOSITS OF FLORIDA, BY JOHN H. DAVIS, JR.

REVIEW BY ROBERT B. CAMPBELL[1]
Gulf Hammock, Florida

"The Peat Deposits of Florida, Their Occurrence, Development and Uses," by John H. Davis, Jr. *Florida Geol. Survey Bull. 30* (Tallahassee, 1946).

Although Florida is not generally considered to be among the mineral-rich states of the Union some of its deposits are of considerable significance. Its phosphate industry is well known and among its lesser resources are extensive deposits of peat. In Florida there are about 3,500 square miles of peat area, containing more than 1,750,000 tons of air-dry peat, which represents one third of the peat resources of the United States. Since the total value of peat and peat lands in the United States is estimated to be worth about $38,000,000, Davis thinks that "this is no mean resource" and after several years investigation has written this bulletin to share his knowledge about, and enthusiasm for, the peat possibilities of Florida. It is comprehensive, well written in an easy, running style, and is well illustrated by photographs, maps, and cross sections. The author is a botanist, now on the faculty of the University of Florida, and naturally has not slighted interest in the floral content and character of the deposits, but he has kept uppermost the economic aspects as indicated in the sub-title. The bulletin is written for the people of Florida, calling attention to the resources at hand and opportunities for development, but the data presented are of significant interest to the botanist and geologist.

After discussing the nature, origin, kinds, and composition of peats in general (Part I), leading to a description of the Florida peats and peat deposits in particular (Part II), Davis outlines the kinds of peat as "Marsh or Low Moor," "Forest Swamp Peats and Mucks," and "Sedimentary Plastics, Aquatic Peats, and Muds" with their occurrence: in the Everglades (more than 1,750,000 acres); in the coastal mangrove swamps and salt marshes (90,000 acres); in the Lake Istapoga marsh (35,000 acres); in the upper St. Johns and Fellsmere marshes (85,000 acres); in the Apopka marsh (15,550 acres); in the Peace Creek area (15,000 acres); in the many small areas of Lake County (11,500 acres); in the Oklawaha valley (5,000 acres); and in the area near Floralhome (4,000 acres). In addition there are many local areas with deposits of peat, limited in quantity but of good quality and economic because of ease of handling and nearness to market.

Part III will particularly engage the interest of the readers of the A.A.P.G. *Bulletin* for herein the author devotes his attention to the geology of the peat deposits and some of the buried derivatives of peat. He notes a relation of the deposits to a number of probable causes: changes of sea-level during the Quaternary and Recent; formation of basins by erosion, subterranean solution, and the formation of hills and dunes; and the subsequent filling in of such basins by the formation of peat and muck. Although he specifically disclaims (p. 167) any responsibility for the theory of C. Wythe Cooke involving inter-glacial terraces as features of Florida's physiography, he ascribes the formation of a large part of the peat deposits to the filling of ponds formed on such terraces. He summarizes:

> In general, the low sea levels of the Nebraskan, Kansan, Illinoian, and Wisconsin glacial ages were followed by high sea levels of the Aftonian, Yarmouth, Sangamon, and Recent interglacial and post-glacial ages respectively. The Wisconsin age had a short deglaciation substage that divides

[1] Consulting geologist. Review received, March 31, 1947.

it into Early Wisconsin or Iowan, the intraglacial Peorian or Pamlico high sea level stage, and the Late Wisconsin low sea level stage, which was followed by the post-glacial high sea levels. During the Sangamon interglacial a rise of sea level occurred in three stages, the Wicomico at 100 feet, the Penholloway at 70 feet, and the Talbot at 42 feet. During the interglacial deglaciation the sea levels rose to approximately 25 feet in Florida, covering all of the Everglades and most of the St. Johns River Valley. In southern Florida and along the coasts the effects of the Pamlico sea of the Mid-Wisconsin and of rises in sea level since the late Wisconsin have had a great influence on the physiographic features and water conditions, and consequently on peat formation.

The effects of the water level changes during the Sangamon interglacial seas, the Talbot, Penholloway, and Wicomico sea level stages, are not so apparent as the Pamlico and postglacial changes, but they also affected peat deposits. The older Yarmouth and Aftonian interglacial ages left little or no effects on topography or peat deposits.

In the Everglades the underlying marl, sand, and rock had no influence on the development of the peat beyond supplying an impervious floor which prevented underground drainage. This is particularly noted in the area underlain by the Lake Flirt marl and Fort Thompson fresh-water limestone in the northern part of the Everglades. In the southern part, where the porous Tamiami limestone is the underlying formation, there is less peat, from which fact Davis infers a causal connection through less water being accumulated. He notes a normal stratification of peat deposits of a fibrous peat over an aquatic, sedimentary peat. Figure 14 of the bulletin gives a cross section of the Everglades showing the relation of the peat to underlying formations there. Davis summarizes that

It is likely that rise of water in lakes, marshes and other places where peat was deposited is due mainly to both decrease in ground water drainage and regional rise of water.

Occurrences of buried peat furnish fragmentary data for inferences concerning the geologic history of Florida, particularly with reference to climate. To determine this numerous analyses of pollen were made. It showed the flora to fall naturally into two groups, those of the oaks, pines, ferns, grasses, and other found to-day in Florida, and those of fir, spruce, *et cetera*, characteristic of a climate not now found closer than 300 miles from northern Florida. From this Davis italicizes:

Thus we may conclude that the time when the fresh water peat layer with spruce and fir pollen was formed was probably a glacial age of cooler climate than the present, and a lower sea level, which was followed by a warmer climate and a higher sea level. This cold interval may have been the Late Wisconsin glacial age and the warmer time the post-glacial.

The utilization of the peats of Florida is the subject of Part IV in which it is pointed out that the total peat area of all counties is approximately 2,250,000 acres (1,900,000 acres of which are in the Everglades), with only about 380,000 of these peat and muck areas being under cultivation. The great sugar-producing area and thousands of acres of great truck farms of the Lake Okeechobee area are located on the Everglades peat and muck areas and the prolific yield from these farms has led local enthusiasts to proclaim the ability of the Everglades to feed the world. However, to date, the great problem of farming in these areas is not the type of soil but water control, a problem awaiting the skill of geologist and engineer.

Although only about 750,000 tons of dry peat—representing less than 1,000 acres—has been used for various purposes in the last forty odd years, Davis is enthusiastic about the possibilities for more utilization of the Florida deposits, pointing out that

the expansion of industries in Florida greatly depends on the development of cheaper power from cheaper fuels of which peat may be one. Consequently, if peat could be mined, processed, and burned efficiently on a large scale this abundant resource of the state might produce the needed cheaper power for industrial expansion.

To explore these possibilities a series of tests was instituted, leading to some interesting conclusions:

(1) if practical means for burning peat could be developed and the steam power used to generate

electricity a total of 100,000,000 kilowatt hours could be obtained from 500 acre feet of Everglades saw grass peat; (2) if the efficiency of burning peat and generating electricity was one kilowatt hour per 15,000 British thermal units, the figures indicate that an area in the Everglades of 36 square miles and 6 feet deep might be used to develop 23,000,000,000 kilowatt hours. This is enough to supply a city of 200,000 for about 40 years.

Other uses for the utilization of peat are discussed, in agriculture, distillation products, those based on physical characteristics, and various minor uses. Of interest is the account of the experiments to determine the fitness of these peats for the newly flourishing plastic industry. It was noted that Everglades peat did not have as favorable yield of wax as had been anticipated but the results showed that many Florida peats contain more than 40 per cent lignin, a high percentage. The best results reported were obtained from a mixture of phenol-formaldehyde resin with about 50 per cent peat. The tests on the whole, however, indicated that the use of untreated peat as a filler in plastics is, in the present economic state of the industry at least, unsatisfactory. Nevertheless, tremendous research effort is being expended on plastics and it may be confidently expected that the chemist and the plastic manufacturer will iron out the difficulties encountered and take advantage of this generous resource.

For A.A.P.G. readers the chief contribution of this bulletin lies in the data pertinent to the geological history of the Florida peninsula, but in its economic aspects it will be of interest to all who are concerned with the whole future of the "hydrocarbon world." Appreciation is due the author for his attractive presentation of the material and to Herman Gunter, director of the Florida Geological Survey, for its publication. Copies of the bulletin may be had, by request to the Survey at Tallahassee, Florida, for the cost of postage and handling.

STATISTICS OF OIL AND GAS DEVELOPMENT AND PRODUCTION BY A.I.M.E. PETROLEUM DIVISION

REVIEW BY WALTER A. VER WIEBE[1]
Wichita, Kansas

Statistics of Oil and Gas Development and Production, assembled by the Committee on Production (Statistical) of the Petroleum Division, A.I.M.E. 444 pp. Published by the Institute, 29 West 39th Street, New York (1946).

The Production Statistics published by the Petroleum Division of the Institute of Mining and Metallurgical Engineers during the last 20 years have been of great value to all persons connected with oil or gas production. The volume for 1945 contained 396 pages and included various papers on scientific and engineering phases of production. A poll of the members of the Petroleum Division taken in 1945 to determine the usefulness of the volume indicated that many members as well as many non-members did not particularly need the scientific, technologic and engineering papers. Therefore, it was decided that two volumes should be published in 1946. The first volume of the two was reviewed in the April number of the *Bulletin* (pp. 779–780 of Volume 31).

In the present volume the usual high quality and excellence of the data which characterized past volumes of this series will be noted. The men who send in the tables on various parts of the United States and for foreign countries evidently try hard to get the last item of value which should be put on record.

In the present volume our members will find a very interesting historical summary of efforts made to find oil or gas in Alabama, Georgia, and Florida. The article on Arkansas

[1] Professor of geology, University of Wichita. Review received, May 12, 1947.

contains a map on which are shown (by symbols) the "crew weeks" for gravity meter and magnetometer work as well as for seismograph work separately. The number of "crew weeks" for each county in the state is indicated.

It appears from the report that the demand for oil in California was so acute during 1945 that more than 15 million barrels had to be imported from Texas and the Rocky Mountain areas. The report on Illinois as usual is exhaustive. The report on Indiana also is complete. The report on Kansas does not include the production statistics for the eastern half of the state. The report for Kentucky shows that this state for the first time in its long history was able to pass the 10-million-barrel mark for production of oil.

Louisiana apparently has a very large reserve of gas which is estimated to total more than 17 trillion cubic feet. For Mississippi, our readers will find a very interesting summary of the early history of exploration. There is also a complete set of data on salt domes in the form of a convenient table. For Nebraska a list of wildcat wells drilled during 1945 is included. In New Mexico deeper drilling has finally resulted in a well which stopped just short of 14,000 feet. In New York there is an interesting bit of information on two hitherto unrecognized formations. A deep well at Arcade [in Wyoming County] found what may turn out to be wholly unexpected middle and lower Cambrian strata in the southwestern part of the state. The base of the Potsdam formation was found at 6,460 feet and the two new formations continue on down to a total depth of 7,126 feet.

In Ohio it appears that 55 per cent of all effort was given over to drilling deep wells into the Clinton formation. There were two deep tests drilled which penetrated the Trenton and older strata. In Oklahoma the drilling along the eastern edge of the Anadarko basin forms the most interesting part of the present report. Interesting also is the fact that 110 new gas wells were drilled in the Panhandle part of the large Hugoton gas field. In Pennsylvania the drilling of horizontal holes at Franklin in Venango County has been abandoned with disappointing results.

For the Rocky Mountains states there is an interesting review of developments during the 6 years preceeding 1945. Four new pools were discovered in the state of Wyoming during 1945. In Texas one of the highlights is the record of the very deep test drilled by the Phillips Petroleum Company (Schoeps No. 3) on the flanks of the Millican dome in Brazos County (90 miles east-northeast of Austin and about the same distance southeast of Waco). This test reached the depth of 16,665 feet and ended in the Glen Rose formation, passing through the thick Ferry Lake massive anhydrite found in East Texas. In West Texas the deep well in Gaines County which is producing from the Devonian system at the depth of 11,422 feet is described. It is notable that the district of West Texas produced more oil in 1945 than any state in the Union except California. The Ordovician fields alone accounted for more than 11 million barrels of the 1945 production.

Production in foreign lands are touched on rather lightly. Nevertheless, we are grateful to the Institute and its correspondents in foreign lands for the information supplied by them. There is a good map of Argentina which shows the four main producing areas of that country. One large new oil field was found in Caleta Olivia about 100 kilometers south of Comodoro Rivadavia. The report on Bahrein and Saudi Arabia includes data on oil production for the war years as well as for 1945. The number of wells drilled here to the end of 1945 is 74, of which 12 are shut in. The 62 producers have put out a total of 70½ million barrels of oil to January 1, 1946. These are significant figures. For Brazil there is a good map showing the four pools producing oil at the present time. Nearly 200,000 barrels of oil have been produced in Brazil to the close of 1945. In Canada nothing sensational is reported for the year 1945. The report on Colombia gives statistics for 1941 as well as for 1945 in order to make the record complete for that country. Total production during 1945 amounted to nearly 23 million barrels of oil, most of which came from the De Mares Concession.

No new fields were discovered in Ecuador during 1945 and somewhat more than $2\frac{1}{2}$ million barrels of oil was produced from the old fields. The oil fields in Egypt have produced more than 75 million barrels of oil. Brief summaries for Irak and Iran suggest that these areas will dominate the oil picture of the future. Venezuela showed a wonderful upsurge in production during 1945 rising from 760,000 barrels per day at the beginning of the year to more than 1 million barrels per day at the close of the year.

THE SCHIST SURFACE OF THE WESTERN LOS ANGELES BASIN BY J. LLOYD WHITE

REVIEW BY JOHN L. FERGUSON[1]
Tulsa, Oklahoma

"The Schist Surface of the Western Los Angeles Basin," by J. Lloyd White. *Summary of Operations, California Oil Fields*, Vol. 32, No. 1 (San Francisco, January–June 1946, published 1947), pp. 3–12; 2 tables, 1 pl.

This brief report covering the oil production from the schistose formation of the western Los Angeles Basin, gives a concise picture of the geological condition involved in this unusual occurrence. The productive areas are considered in some detail and the non-productive schist wells are also described as to structural position, depth of penetration and evidence of oil. A table of selected wells which penetrated the schist is included, with a second table of significant non-schist deep wells.

The contour map of the top of the schist indicates that the production is adjusted to the axis of schist ridges, which are not necessarily conformable to overlying sedimentary axes. The oil occurs in fractures in the schist to depths greater than 680 feet in the formation and initial productions up to 4,000 barrels per day have been reported.

[1] Amerada Petroleum Corporation. Review received, May 14, 1947.

RECENT PUBLICATIONS

ARABIA

Saudi Arabia, with an Account of the Development of Its Natural Resources, by K. S. Twitchell. 192 pp., illus., maps, tables. 5×8 inches. Cloth. Princeton University Press, Princeton, New Jersey (1947). Price, $2.50.

ARGENTINA

*"Los depósitos terrestres del Cretácico medio y superior del Neuquén y sur de Mendoza" (Terrestrial Deposits of Upper and Middle Cretaceous in Neuquén and Southern Mendoza), by Abel Herrero Ducloux. *Y. P. F. Bol. Informaciones Petroleras*, Vol. 24, No. 271 (Buenos Aires, March, 1947), pp. 171–78; 2 figs. In Spanish.

BRAZIL

*"Geological and Geophysical Work in Bahia in 1945," in *Relatorio de 1945*, published by Conselho Nacional do Petroleo (Rio de Janeiro, 1947), pp. 71–100, Figs. 5–18, photographs 16–30. Geological maps and stratigraphic sections. Work of DeGolyer and MacNaughton, Garner, Meyer, Shearer, Keller, Guedes, Gomes, Sollero, Pack, Almeida, Wayne H. Denning, *et al.* In Portuguese.

COLORADO

*"Cenozoic Physiographic History of the Front Range, Colorado," by Ernest E. Wahlstrom. *Bull. Geol. Soc. America*, Vol. 58, No. 7 (New York, July, 1947), pp. 551–72; 7 figs.

DENMARK

*"Geology of Denmark," *anon. World Oil*, Vol. 126, No. 6 (Houston, July 7, 1947), International Section, pp. 23–25, map.

ENGLAND

*"The Supposed Cambrian Foraminifera from the Malverns," by Alan Wood. *Quar. Jour. Geol. Soc. London*, Vol. 102, Pt. 4, No. 408 (April, 1947), pp. 447–56; discussion, 456–60; 3 pls., 1 fig.

FRANCE

**Soc. Geol. France Compte Rendu Sommaire Séances Nos. 9–10* (Paris, June, 1947), pp. 177–216. Titles and summaries of papers presented orally and in writing at the Society meetings of May 19 and June 2, 1947. Summaries published bi-monthly. Annual subscription, 250 Fr.; this number, 30 Fr.

GENERAL

*"Graptolites of North America," by Rudolf Ruedemann. *Geol. Soc. America Mem. 19* (New York, June, 1947). 652 pp., 92 pls., 1 fig.

*"Effect of Bacteria on Oil Production," by Charles J. Deegan. *Oil and Gas Jour.*, Vol. 46, No. 7 (Tulsa, June 21, 1947), pp. 78–79, 113–114; illus.

*"Salt Water Yardstick," *anon. The Link*, Vol. 12, No. 6 (Carter Oil Company, Tulsa, June, 1947), pp. 8–11; illus.

**Tecto-orogeny*, by V. G. Bondarchuk. 262 pp. 93 figs., 1 folded tectonic map of Eurasia. Paper cover. 6×8.75 inches. The Geological Faculty of the State University of Kiev, Ukraine (1946). In Russian. 3-page summary in English.

*"Oil—Its Origin and Accumulation," by F. M. Van Tuyl and Ben H. Parker. *World Oil*, Vol. 126, No. 7 (Houston, July 14, 1947), pp. 39–44; 46; 2 figs. *Ibid.*, No. 8 (July 21), pp. 48–52.

*"Contouring Fault Planes," by W. A. Reiter, *ibid.*, pp. 34–35; 3 figs.

"Bibliography of North American Geology, 1944 and 1945," by E. M. Thom. *U. S. Geol. Survey Bull. 952* (May, 1947). 496 pp. Sold by Supt. Documents, Govt. Printing Office, Washington 25, D. C. Price, $1.00.

"Corrections for Bibliography of North American Geology, Bulletins 937, 938, and 949." Separate sheet from Bull. 952, containing corrections for the 3 Bulletins previously published. Obtainable from Director, U. S. Geological Survey, Washington 25, D. C. Free.

*"On the Main Types of Oil- and Gas-Bearing Platform Structures," by N. J. Uspenskaya. *Comptes Rendus (Doklady) Acad. Sci. URSS*, Vol. 53, No. 4 (Moscow, 1946), pp. 347–50; 2 figs. 1 table. In English.

*"Olds' Decline Curves," by E. Russell Lloyd. *World Oil*, Vol. 126, No. 8 (Houston, July 21, 1947), pp. 35–37; 6 figs.

*"Torsion Balance Surveys of Inundated Areas," by K. F. Hasselmann. *Ibid.*, pp. 38–40; 2 figs.

GULF COASTAL PLAIN

"Correlation Chart for the Outcropping Tertiary Formations of the Eastern Gulf Region," by F. Stearns MacNeil. *U. S. Geol. Survey Prelim. Chart 29*, Oil and Gas Investig.

Ser. (July, 1947). New correlations in Mississippi, Alabama, Georgia, and Florida. Sheet, 22×23 inches. For sale by Director, U. S. Geol. Survey, Washington 25, D. C. Price, $0.20.

JAPAN

*"Petroleum Resources and Production in Japan," *anon. Supreme Commander for the Allied Powers, Natural Resources Section Rept. 80, General Headquarters* (Tokyo, June 25, 1947). 54 pp., 13 figs., 5 tables. Contains list of all Natural Resources Section published reports. Requests for copies should be addressed to Chief, Civil Affairs Division, War Department, Washington 25, D. C.

KANSAS AND COLORADO

*"Subsurface Geologic Cross Section from Scott County, Kansas, to Otero County, Colorado," by John C. Maher. *Kansas Geol. Survey Prelim. Cross Section 4*, Oil and Gas Investig. (Lawrence, 1947). 11 pp. of text and folded section.

LOUISIANA

*"The Delhi Field Today," by O. W. Willcox. *World Petroleum*, Vol. 18, No. 7 (New York, July, 1947), pp. 41–45; 6 figs.

MISSISSIPPI

*"History of Development in the Southeastern States," by Clyde W. Alexander. *Independent Monthly*, Vol. 18, No. 3 (Tulsa, July, 1947), pp. 11–15, 38–40; 2 figs.

NETHERLANDS

*"Stratigraphie et Paleontologie Animale du Terrain Houiller du Peel" (Stratigraphy and Paleontology of the Coal Measures of Peel), by S. van der Heide. Mededeelingen van de Geologische Stichting, Ser. C, IV, 3, No. 4. Ernest van Aelst, Uitgevers-Mij., Maastricht, Netherlands (1946). 98 pp., 1 pl., 4 figs., 4 tables, 1 stratigraphic section, bibliography. 9×11.75 inches. Paper cover. Introduction in Dutch. Text in French.

*"Foraminifera from the Middle Eocene in the Southern Part of the Netherlands Province of Limburg," by R. C. Van Bellen. *Ibid.*, Ser. C, V, No. 4 (1946). 144 pp., 13 pls., 11 figs., 1 table, bibliography. 7.75×10.5 inches. Paper cover. In English.

*"The Foraminifera from the Hervian (Campian) of Southern Limburg," by E. Schijfsma. *Ibid.*, Ser. C, V, No. 7 (1946). 174 pp., 10 pls., 5 figs., 4 tables, bibliography. 7.75×10.5 inches. Paper cover. Foreword in Dutch. Text in English.

OKLAHOMA

*"Coring the Burgess Sandstone," by Carl A. Moore. *Oil Weekly*, Vol. 126, No. 3 (Houston, June 16, 1947), pp. 38–43; 3 figs.

*"Southern Oklahoma Oil," by Frank Gouin. *Oil Weekly*, Vol. 126, No. 4 (Houston, June 23, 1947), pp. 34–42; 2 photographs, 2 figs., 1 table.

RUSSIA

*"On the Relation of the Artinskian Reef Massifs of the Bashkirian Sub-Ural Depression with Tectonics," by N. J. Uspenskaya. *Bull. Acad. Sci. URSS*, Ser. Geol., No. 3 (Moscow, 1946), pp. 57–68; 4 figs. In Russian, with summary in English.

TEXAS

*"Modern Seismic Techniques Applied to Geophysical Exploration in West Texas," by Sidon Harris. *Oil and Gas Jour.*, Vol. 46, No. 11 (Tulsa, July 19, 1947), pp. 60–63; 6 figs.

VENEZUELA AND TRINIDAD

**The Geology of Venezuela and Trinidad*, by Ralph Alexander Liddle. 2d ed., revised and enlarged (1946). 890 pp. 6×9 inches. 180 halftones, 27 sections and maps, correlation chart, geologic map, and map showing mineral deposits, major structural features, and exploratory tests for oil. Contains bibliography of all important works on Venezuela and Trinidad. Green cloth, gold title. Order from Paleontological Research Institution, 126 Kelvin Place, Ithaca, New York. Price, postpaid, $10.

WYOMING AND MONTANA

"Structure Contour Map of the Big Horn Basin, Wyoming and Montana," by William G. Pierce, David A. Andrews, and Jewell Kirby Keroher. *U. S. Geol. Survey Prelim. Map 74*, Oil and Gas Investig. Ser. (June, 1947). 38×48 inches. Scale, 1 inch equals 3 miles. Oil and gas fields are shown by color overprint. 200-foot structural contours on top of Frontier formation. An extensive revision of *Prelim. Map 3*, issued in 1944. Address mail orders to: Director, Geological Survey, Washington 25, D. C. Price, $0.50.

"Geologic Map of the Big Horn Basin, Wyoming and Montana, Showing Terrace Deposits and Physiographic Features," by D. A. Andrews, W. G. Pierce, and D. H. Eargle. *Ibid., Map 71* (August, 1947). 44×64 inches.

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* "*Journal of Paleontology* (Tulsa, Oklahoma), Vol. 21, No. 4 (July, 1947).

"Brachiopoda of the Percha Shale of New Mexico and Arizona," by Merrill A. Stainbrook.

"Cretaceous Microfossils of the Vermilion Area, Alberta," by Arthur W. Nauss.

"The Genotype of the isoarca (Class Pelecypoda)," by David Nicol.

"Tropical American Species of *Glycymeris* from the Tertiary of California, and a New Species from Panama," by David Nicol.

"A *Koninckioceras* from the Lower Permian of North-Central Texas," by A. K. Miller and Augusta Hasslock Kemp.

"Index to New Genera, Species and Varieties of Foraminifera for the Year 1945, with Supplements for the Period 1939–1944, and Addenda for 1942–1945," by Hans E. Thalmann.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 8 (AUGUST, 1947), PP. 1524-1531

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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SAN ANTONIO REGIONAL MEETING, NOVEMBER 5-6, 1947

The executive committee has accepted the invitation of the South Texas Section to hold a mid-year meeting in San Antonio. The annual meeting of the Section is to be designated by the Association as an A.A.P.G. regional meeting, to be held at the Plaza Hotel, November 5 and 6, 1947. The technical program is planned tor those two days and fields will be arranged for the following two days, November 7 and 8, presenting geologic features of Southwest Texas, covering stratigraphy from early Mesozoic to Recent, tectonics and structure, and detailed papers on outstanding fields of the region.

Guy E. Green, president of the South Texas Section, has appointed Robert N. Kolm as chairman of arrangements. Further notices will be forthcoming, particularly about the proper method for making hotel reservations.

PACIFIC SECTION ANNUAL MEETING, PASADENA, NOVEMBER 6–7, 1947

The 24th annual meeting of the Pacific Section of the Association has been announced for November 6 and 7, 1947. Breaking a custom of years of being held at Los Angeles, it will be at Pasadena this year. The Huntington Hotel is to be headquarters. The luncheon will be held on Thursday, November 6, and the dinner-dance on Friday, November 7. Chairmen for the occasion are: general arrangements, HARVEY W. LEE, Union Oil Company of California, Los Angeles; program chairman, JAMES C. KIMBLE, General Petroleum Corporation, Bakersfield; program sub-chairman, ROBERT T. WHITE, Barnsdall Oil Company, Los Angeles. Officers of the Section are: president, MARTIN VAN COUVERING; vice-president, W. P. WINHAM; secretary-treasurer, C. W. JOHNSON.

ST. LOUIS REGIONAL MEETING, JANUARY 14–15, 1948

The executive committee has accepted the invitation of the Illinois Geological Society to hold an Association regional meeting in St. Louis, Missouri, January 14–15, 1948, under the sponsorship of the Society. The technical program will be concentrated on the Great Lakes-Appalachian region. Short field trips are under consideration. The Jefferson is the headquarters hotel. Members are requested to look for further announcements, particularly with respect to the method of making hotel room reservations. E. E. REHN is president of the Illinois Geological Society, and DARSIE A. GREEN is in charge of the program.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 31, NO. 8 (AUGUST, 1947), PP. 1532-1536

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The American Commission on Stratigraphic Nomenclature, RAYMOND C. MOORE, chairman, has arranged for distribution of its publications. Complimentary copies of Notes 1 and 2 as published in the A.A.P.G. *Bulletin*, Vol. 31, No. 3 (March, 1947), and subsequent notes, may be obtained, on request, from the Geological Society of America, 419 West 117th Street, New York 27, N. Y.

CHARLES A. SHAW, consulting petroleum geologist, has moved his office to 313 North Colorado Street, Midland, Texas.

GEORGE WILLIAM BEER recently resigned from the United States Geological Survey to accept a position as field geologist with the Carter Oil Company at Vernal, Utah.

A. C. TROWBRIDGE, State geologist of Iowa, has resigned his position. H. GARLAND HERSHEY, assistant State geologist has been named as his successor.

EUGENE A. STEPHENSON, chairman of the department of petroleum engineering at the University of Kansas, has resigned after occupying the position for 10 years. He is succeeded by REX W. WOODS.

VIE CHOW JUAN has resigned as professor of geology and chairman of the department of geology, Peiyang University, Tientsin, China, to join the staff of the department of geology, National Peking University, Peiping, China.

CECIL G. LALICKER has resigned from the faculty of geology at the Colorado Schoo of Mines to accept a position as professor of geology at the University of Kansas, Lawrence, Kansas.

The Michigan Geological Society has elected officers: president, CHARLES K. CLARK, Pure Oil Company, Saginaw; vice-president, W. A. KELLY, Michigan State College, East Lansing; secretary-treasurer, HARRY J. HARDENBERG, Michigan Geological Survey, Lansing; business manager, JACK MORTENSON, Sohio Petroleum Company, Mt. Pleasant.

RALPH W. WILPOLT, formerly with the New Mexico School of Mines, is in the employ of the American Smelting and Refining Company. His address is chief of the geology department, Mina Tiro General Charcas, San Luis Potosi, Mexico.

JAMES H. C. MARTENS, formerly with the West Virginia Geological Survey, is with the Bureau of Mineral Research, Rutgers University, New Brunswick, New Jersey.

CLARENCE P. DUNBAR, recently in the School of Geology at Louisiana State University, may be addressed in care of the Office of the President, University of Louisville, Louisville, Kentucky.

KAROL BOHDANOWICZ, aged 82 years, director of the National Geological Institute, Warsaw, Poland, died June 7.

WILLIAM M. BRODERICK has resigned from the geological department of The Texas Company and has accepted a position with the Anderson-Prichard Oil Corporation, Wichita, Kansas.

LELAND W. JONES, who has been with the Anderson-Prichard Oil Corporation several years at Oklahoma City, has left to engage in consulting work.

FRED M. HAASE, having resigned from the Shell Oil Company, Inc., may be addressed at 959 Lee Street, New Braunfels, Texas.

New officers of the Corpus Christi Geological Society, Corpus Christi, Texas, are: president, DALE L. BENSON, Sinclair Prairie Oil Company; vice-president, ROBERT D. HENDRICKSON, Tide Water Associated Oil Company; secretary-treasurer, H. C. COOKE, c/o O. G. McClain, 224 Nixon Building.

JOHN D. MOODY is with the Kuwait Oil Company, Ltd., Kuwait, Persian Gulf.

CHESTER R. THOMAS is chief geologist for Corporación de Fomento de la Producción, Chile, at Punta Arenas, Chile.

J. D. WEIR is chief geologist for The California Standard Company at Calgary, Alberta, Canada.

JOHN C. OSMOND, JR., has graduated from the University of Texas with a major in geology. He is in the employ of the Humble Oil and Refining Company as a junior geophysicist.

H. TRAVIS BROWN resigned as division geologist for the Cities Service Oil Company, Bartlesville, Oklahoma, effective July 1, to become general manager of The Geolograph Company, Inc., of Oklahoma City.

Ninety friends of E. WAYNE GALLIHER have contributed a memorial fund to the School of Mineral Sciences of Stanford University. The purpose of the fund is to start the "Galliher Microphotograph Laboratory." The committee in charge of the fund was composed of R. T. WHITE, chairman, E. R. ATWILL, R. W. SHERMAN, and VINCENT W. VANDIVER, trustees.

JOHN B. PATTON has left the Magnolia Petroleum Company to become research assistant in economic geology at Indiana University, Bloomington, Indiana.

WILLIAM W. DAVIS graduated from Princeton University in June and is now employed by the Sun Oil Company in the gravity meter department. He has been stationed at San Angelo, Texas.

W. K. DAVIS, formerly with the El Paso Natural Gas Company, is vice-president in charge of operations of the Western Natural Gas Company, Houston, Texas.

HENRY C. CORTES, JR., recently employed by the Humble Oil and Refining Company, is in business for himself at Dallas, Texas.

A. I. LEVORSEN, head of the School of Mineral Sciences at Stanford University, California, was honored with the degree of doctor of science conferred by the University of Minnesota in June.

The American Petroleum Institute will meet at the Stevens Hotel, Chicago, November 10–13, 1947.

The International Petroleum Exposition will be held at Tulsa, Oklahoma, May 15–22, 1948.

F. C. MACKNIGHT, formerly with The Texas Company, New Orleans, has been appointed professor of geology and geography at Evansville College, Evansville, Indiana. This is a new department at Evansville College and it plans to specialize in the training of petroleum geologists.

WINTHROP PERRIN HAYNES, geologist for the Standard Oil Company (New Jersey), has been appointed visiting lecturer on geology for the academic year 1947–1948 at Harvard University. He will give courses in petroleum geology.

CUMMINS, BERGER & PISHNY, engineers and geologists of Fort Worth and Houston, announce as associates, IRA A. BRINKERHOFF, geologist, in charge of the new Houston office, and V. ROBERT KERR, seismologist, in charge of seismic interpretation in the Fort Worth office.

DONALD M. OLIVER and FRED F. KOTYZA announce the formation of a partnership under the name of OLIVER & KOTYZA to serve as consultants in petroleum geology and petroleum economics and as appraisers of oil properties, with offices at 113 West Texas, Midland, Texas.

The 24th annual meeting of the Pacific Section of the Association will be held at the Huntington Hotel, Pasadena, California, November 6 and 7. The luncheon will be held on Thursday, the 6th, and the dinner-dance on Friday, the 7th. HARVEY W. LEE is general chairman, JAMES C. KIMBLE is program chairman, and ROBERT T. WHITE is program subchairman.

The Northern California Geological Society met at the Engineers Club, San Francisco, June 30. HARRY TURVER, of the Standard Oil Company Los Angeles office, discussed "Marine Life," and showed motion pictures in color.

The United States Civil Service Commission, Washington, D. C., announces an examination for probational appointment to the position of geologist, $4,149 to $7,012 a year (grades P-3 to P-6). Competitors for these positions will not be required to take a written test. To qualify, they must have completed either a four-year college course leading to a bachelor's degree in geology, or a time-equivalent combination of study in geology and technical experience. In addition, they must have had professional experience in geology. Graduate study may be substituted for a part of the required experience. Interested persons may obtain information and application forms from most first- and second-class post offices, and from the U. S. Civil Service Commission, Washington 25, D. C.

JOHN L. BIBLE has resigned his position as executive vice-president of the North American Geophysical Company and has established offices as a consulting geophysicist, specializing in gravity and magnetic supervision and interpretation and residual gravity computations and studies. He has joined with U. E. Neese and Fred A. Lauterbach in organizing the Tidelands Exploration Company for performing precise gravity surveys on land and water. The new offices are located at 2626 Westheimer, Houston 6, Texas.

The Geological Forum of the Pacific Section of the Association met at Los Angeles, July 21, under the chairmanship of PAUL HAYES of the Capital Company. The program included the following: "Factors Influencing the Selection of Mud Fluid for Completion of Wells," by HAROLD RADFORD, of the Shell Oil Company; "The San Juan Basin, New Mexico," by BOB MORAN, consultant; and "The Creation of the Universe," by DONUIL HILLIS, of the Capital Company.

M. M. LEIGHTON, for the past 24 years chief of the State Geological Survey, at Urbana, Illinois, was cited by the State University of Iowa, at its recent commencement, as a "Distinguished Alumnus," in recognition "of his eminence in his chosen field of geology and of his contributions to the public welfare.

BYRON RIFE has been elected vice-president of the Holly Development Company, oil subsidiary of the Holly Sugar Company. He will have charge of all Texas activities of the company, with offices in the Milam Building, San Antonio, Texas.

Members who have not filled and returned the Scientific Manpower questionnaires, recently mailed, are requested to send them promptly to DAVID M. DELO, chief of the Scientific Manpower Branch, Research Group, War Department General Staff, Washington 25, D. C., in the envelope which accompanied the questionnaire.

CARL A. MOORE is associate professor of geology at the University of Oklahoma, Norman, Oklahoma.

The address of J. W. KISLING, JR., formerly with the Amerada Petroleum Corporation and a consulting geologist in Tulsa, Oklahoma, is Sinclair Petroleum Company, Box 348, Addis Ababa, Ethiopia.

H. WESTON ROBBINS, recently with the Bureau of Reclamation at Denver, Colorado, is in the employ of the Superior Oil Company of Colombia, Apartado Aéreo 4809, Bogota, Colombia.

EDWARD B. WALKER, III, has left the Massachusetts Institute of Technology. He may be addressed at Apartado 45, Barcelona, Venezuela.

EDWARD A. KOESTER has resigned as vice-president and director of Darby and Bothwell, Inc., at Wichita, Kansas, and is engaged in consulting work. Koester has been in geological work in the Mid-Continent region since 1929. He was secretary-treasurer of the A.A.P.G. for 2 years ending March, 1947. He has opened his office at 302 Orpheum Building, Wichita, Kansas.

IRA H. CRAM, assistant chief geologist of the Pure Oil Company, Chicago, Illinois, and a former president of the A.A.P.G., participated in a recent radio discussion over Northwestern University's Station WGN and the Mutual network, entitled, "Are We Exhausting Our Natural Resources?"

ARTHUR C. BEVAN, State geologist of Virginia, Charlottesville, will join the Illinois Geological Survey, Urbana, on September 15, as principal geologist in charge of the Geological Resources Section, succeeding RALPH E. GRIM who has requested relief from administrative duties to devote more time to the Survey's research program on clay minerals. Bevan will retain his chairmanship of the Division of Geology and Geography of the National Research Council.

R. C. COOPER, of the Sinclair Prairie Oil Company, is in charge of the land and geological work at Evansville, Indiana, succeeding A. H. LLWYD.

ROBERT HENRY ABBOTT, JR., and WALTER W. MCMAHON, both of San Antonio, Texas, have won the Houston Geological Society Merit Award, which is given each year to outstanding geology and petroleum engineering students at Texas A. and M. College, College Station, Texas. The award provides associate membership in the A.A.P.G. Abbott's winning paper was "Productivity Index and Proration." McMahon wrote on "Cycles of Sedimentation." He is with The Texas Company.

CLIFFORD L. MOHR, of Hoover, Curtice, and Ruby, has returned to the United States from Punta Arenas, Chile, after several years in the Spring Hill area, Tierra del Fuego.

R. SARMIENTO-SOTO, chief of the Geological Survey of Columbia, addressed the Universidad Libre forum in Bogota recently on the subject, "Geological Aspects of Oil."

CARLOS A. ANDERSON, JR., is district geologist at McCamey, Texas, for the Texas Pacific Coal and Oil Company.

KENNETH G. REDMAN received his Master's degree in geology at the University of

Kansas in June and is now a junior geologist with the Phillips Petroleum Company at Bartlesville, Oklahoma.

VICTOR E. OPPENHEIM, consulting geologist of Bogota, Colombia, has been travelling in North and Central America this summer.

JOHN DOWNIE FALCONER of London died last April after a long life of geological experience in many parts of the world.

WILMER R. SHIRK, formerly consulting geologist, is in the employ of the Bay Petroleum Company, Wichita Falls, Texas.

ROBERT I. LEVORSEN has received the degree of Master of Arts at the University of California at Los Angeles, and is now with The California Company, temporarily located at Brookhaven, Mississippi.

ARTHUR R. WELLER has graduated from Stanford University, California, and is a trainee with the Shell Oil Company, Inc., at Bakersfield, California.

FOSTER M. MONAHAN, recently with the Stanolind Oil and Gas Company at Midland, Texas, is in the employ of the Ashland Oil and Refining Company at Tulsa, Oklahoma.

E. G. DAHLGREN talked on "Underground Natural Gas Storage," at the meeting of the Oklahoma City Geological Society, July 24.

SHERMAN A. WENGERD has resigned as subsurface research geologist with the Shell Oil Company at Wichita Falls, Texas, to become assistant professor of geology at the University of New Mexico, Albuquerque, New Mexico, effective August 1.

ROBERT L. JOHNSTON has resigned his position as petroleum engineer with the General Petroleum Corporation to accept the position of geologist with the Western Gulf Oil Company at Bakersfield, California.

JAMES D. MORRIS has left the Magnolia Petroleum Company and is now with the Derby Oil Company, Wichita, Kansas.

JOHN THERON SANFORD, recently with the Magnolia Petroleum Company, Oklahoma City, has joined the faculty of Wayne University, Detroit, Michigan.

JOSEPH M. CLARK has resigned from the Tide Water Associated Oil Company geological department at Tulsa, to engage in private consulting practice. His office, temporarily, is 602 South Erie, Tulsa, Oklahoma.

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

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Gravity Meter Exploration Co.
1348 Esperson Bldg., Houston, Tex.
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Shell Oil Company, Inc.
Houston, Texas
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Business Manager - - - - - Colin C. Campbell
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Box 2437 Terminal Annex, Los Angeles 54

Secretary-Treasurer - - - Clifton W. Johnson
430 Richfield Building, Los Angeles 13

Monthly Luncheons: First Thursday each month, Clark Hotel, 426 South Hill St., Los Angeles

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF GEOLOGISTS
DENVER, COLORADO

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Heiland Research Corporation
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1st Vice-President - - - - Robert McMillan
Geophoto Services, Inc.
305 E & C Building

2nd Vice-President - - - - - - A. W. Cullen
1024 Continental Oil Building

Secretary-Treasurer - - - - - - - N. W. Bass
U. S. Geological Survey, 300 New Customhouse

Evening dinner (6:30) and technical program (8:00) first Tuesday each month or by announcement.

FLORIDA

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Box 841
TALLAHASSEE, FLORIDA

President - - - - - - - - - - - H. A. Sellin
Magnolia Petroleum Company
Vice-President - - - - - - - - B. B. Spaulding
The Texas Company, Box 21
Secretary-Treasurer - - - - - Lois J. Schulz
The California Company, Box 371

Meetings will be announced. Visiting geologists and friends are welcome.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

President - - - - - - - - - - E. E. Rehn
Sohio Petroleum Company
Box 537, Mt. Vernon
Vice-President - - - - - - - John B. Patton
Indiana University
Bloomington, Indiana
Secretary-Treasurer - - - - - Charles Doh
Schlumberger Well Surveying Corporation
Box 571, Mattoon
Meetings will be announced.

INDIANA-KENTUCKY

INDIANA-KENTUCKY GEOLOGICAL SOCIETY
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Sohio Petroleum Company, Damron Bldg.
Owensboro, Kentucky
Vice-President - - - - - - George E. Taylor
Continental Oil Company, 606 Division St.
Evansville, Indiana
Secretary-Treasurer - - - - - - - P. L. Keller
Great Lakes Carbon Company, American Bldg.
Evansville, Indiana
Meetings will be announced.

KANSAS

KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

President - - - - - - - - E. Gail Carpenter
Consulting, 240 N. Pinecrest
Vice-President - - - - - - Lee H. Cornell
Stanolind Oil and Gas Company
Secretary-Treasurer - - - - - Don W. Payne
Sinclair Prairie Oil Company

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka.

LOUISIANA

NEW ORLEANS GEOLOGICAL SOCIETY
NEW ORLEANS, LOUISIANA

President - - - - - - - - - D. D. Utterback
Houston Oil Company of Texas
1701 Pere Marquette Bldg.
Vice-President and Program Chairman - - - - - - - - - - - - - - Joe B. Hudson
Humble Oil and Refining Company
Secretary-Treasurer - - - - - - D. N. Rockwood
Union Producing Company, Box 1628

Meets the first Monday of every month, October-May inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

President - - - - - - - - W. E. Wallace, Jr.
Sohio Petroleum Company, Atlas Building

Vice-President - - - - - - - Edward W. Scott
Union Oil Company of California
Ricou-Brewster Building

Secretary-Treasurer - - - - Richard T. Chapman
Stanolind Oil and Gas Company, Box 1092

Meets monthly, September to May, inclusive, in the State Exhibit Building, Fair Grounds. All meetings by announcement.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - - - Charles K. Clark
Pure Oil Company
402 2d Natl. Bank Bldg., Saginaw

Vice-President - - - - - - - - W. A. Kelly
Michigan State College
East Lansing

Secretary-Treasurer - - - Harry J. Hardenberg
Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing

Business Manager - - - - - Jack Mortenson
Sohio Petroleum Company, Mt. Pleasant

Meetings: Monthly, November through May, at Michigan State College, East Lansing, Michigan. Informal dinners at 6:30 P.M., followed by discussions. Visiting geologists are welcome.

LOUISIANA

SOUTH LOUISIANA GEOLOGICAL SOCIETY
LAKE CHARLES, LOUISIANA

President - - - - - - - - Bruce M. Choate
Atlantic Refining Company

Vice-President - - - - - - - - Roy A. Payne
Gulf Oil Corporation

Secretary - - - - - - - - W. Farrin Hoover
Stanolind Oil and Gas Company, Box 54

Treasurer - - - - - - - - - - W. B. Neill
Stanolind Oil and Gas Company

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY
JACKSON, MISSISSIPPI

President - - - - - - - - - - H. L. Spyres
Skelly Oil Company

Vice-President - - - - - - - - R. D. Sprague
Sinclair Wyoming Oil Company

Secretary-Treasurer - - - - - - Carl F. Grubb
Superior Oil Company
Tower Building

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - - - Robert W. Kline
Sinclair Prairie Oil Company, Box 978

Vice-President - - - - - - - - B. W. James
Phillips Petroleum Company, Box 958

Secretary-Treasurer - - - - - W. R. Johnson
The Texas Company Box 539

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

President - - - - - - - - Henry A. Campo
Atlantic Refining Company, Box 169,
Shawnee

Vice-President - - - - - - - Fred J. Smith
Sinclair Prairie Oil Company
Box 991, Seminole

Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Company, Box 169
Shawnee

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - - - - - - Gerald C. Maddox
Carter Oil Company

Vice-President - - - - - - - - - Harold J. Kleen
Skelly Oil Company

Secretary-Treasurer - - - - - - Frederick H. Kate
Shell Oil Company, Inc.
965 First National Building

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon. Y.W.C.A.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

President - - - - - - - - Charles G. Carlson
Consulting Geologist, 922 Thompson Building

1st Vice-President - - - - - - Jerry E. Upp
Amerada Petroleum Corporation, Box 2040

2nd Vice-President - - - - - L. E. Fitts, Jr.
Sinclair Prairie Oil Company, Box 521

Secretary-Treasurer - - - - - - - V. L. Frost
Ohio Oil Company, Thompson Building

Editor - - - - - - - - - Robert F. Walters
Box 661, Gulf Oil Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

PENNSYLVANIA

PITTSBURGH GEOLOGICAL SOCIETY

PITTSBURGH, PENNSYLVANIA

President - - - - - - - - S. S. Philbrick
United States Engineers, 925 New Federal Bldg.

Vice-President - - - - - - John T. Galey
Independent, Box 1675

Secretary - - - - - - - - David K. Kirk
Gulf Research and Development Co., Box 2038

Treasurer - - - - - - - - C. H. Feldmiller
111 Haldane Avenue, Pittsburgh 5

Meetings held each month, except during the summer. All meetings and other activities by special announcement.

TEXAS

PANHANDLE GEOLOGICAL SOCIETY

AMARILLO, TEXAS

President - - - - - - Graydon L. Meholin
Sinclair Prairie Oil Company, Box 1242

Vice-President - - - - - - Paul A. Grant
Gulf Oil Corporation, Box 110

Secretary-Treasurer - - - - - Robert J. Gutru
Cities Service Oil Company, Box 350

Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Herring Hotel. Special night meetings by announcement.

TEXAS

CORPUS CHRISTI GEOLOGICAL SOCIETY

CORPUS CHRISTI, TEXAS

President - - - - - - - - - Dale L. Benson
Sinclair Prairie Oil Company, Box 480

Vice-President - - - Robert D. Hendrickson
Tide Water Associated Oil Company

Secretary-Treasurer - - - - - H. C. Cooke
c/o O. G. McClain, 224 Nixon Building

Regular luncheons, every Wednesday, Petroleum Room, Plaza Hotel, 12:05 Special night meetings by announcement.

EAST TEXAS GEOLOGICAL SOCIETY

TYLER, TEXAS

President - - - - - - - - T. H. Shelby, Jr.
Humble Oil and Refining Company

Vice-President - - - - - - - - - - L. F. Lees
Phillips Petroleum Company
Box 208

Secretary-Treasurer - - - - Walter E. Long
Magnolia Petroleum Company
Box 780

Luncheons: Each week, Monday noon, Blackstone Hotel.

Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

HOUSTON GEOLOGICAL SOCIETY

HOUSTON, TEXAS

President - - - - - - - Charles H. Sample
J. M. Huber Corporation
721 Bankers Mortgage Bldg.

Vice-President - - - - - - - - A. F. Childers
Gulf Oil Corporation, Box 2100

Secretary - - - - - - Hershal C. Ferguson
Consultant, 1208 Esperson Building

Treasurer - - - - - - - - - Eugene L. Earl
Crown Central Petroleum Corporation

Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Rice Hotel. For any particulars pertaining to the meetings write or call the secretary.

DALLAS GEOLOGICAL SOCIETY

DALLAS, TEXAS

President - - - - - - - - - Willis G. Meyer
Meyer and Achtschin
502 Continental Building

Vice President - - - - - - John M. Clayton
Seaboard Oil Company
1400 Continental Building

Secretary-Treasurer - - - - - W. W. Newton
Geotechnical Corporation, Box 7166

Meetings: Monthly luncheons by announcement. Special night meetings by announcement.

FORT WORTH GEOLOGICAL SOCIETY

FORT WORTH, TEXAS

President - - - - - - - - - C. D. Cordry
Gulf Oil Corporation
Box 1290

Vice-President - - - - - - - R. H. Schweers
The Texas Company, Box 1720

Secretary-Treasurer - - - - - - R. W. Dudley
Pure Oil Company
Box 2107

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

NORTH TEXAS GEOLOGICAL SOCIETY

WICHITA FALLS, TEXAS

President - - - - - - - - - Dolph E. Simic
Bay Petroleum Corporation

Vice-President - - - - - - - Lynn L. Harden
Sinclair Prairie Oil Company

Secretary-Treasurer - - - - - - D. T. Richards
Consulting, 1709 Buchanan Street

Meetings: Each week, Tuesday, 12:30 P.M., Texas Electric Auditorium; Each month, first Thursday evening. Special night meetings announced. All geologists always welcome.

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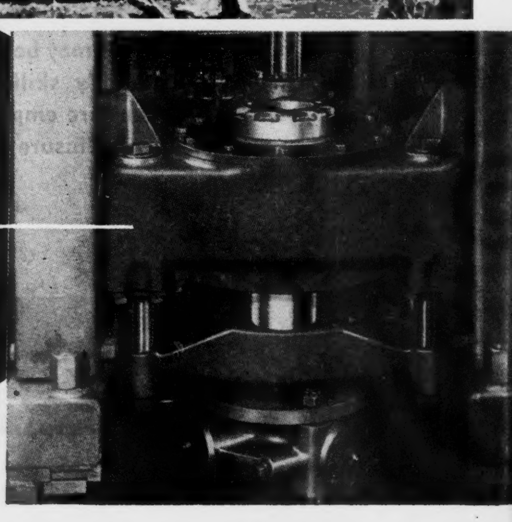

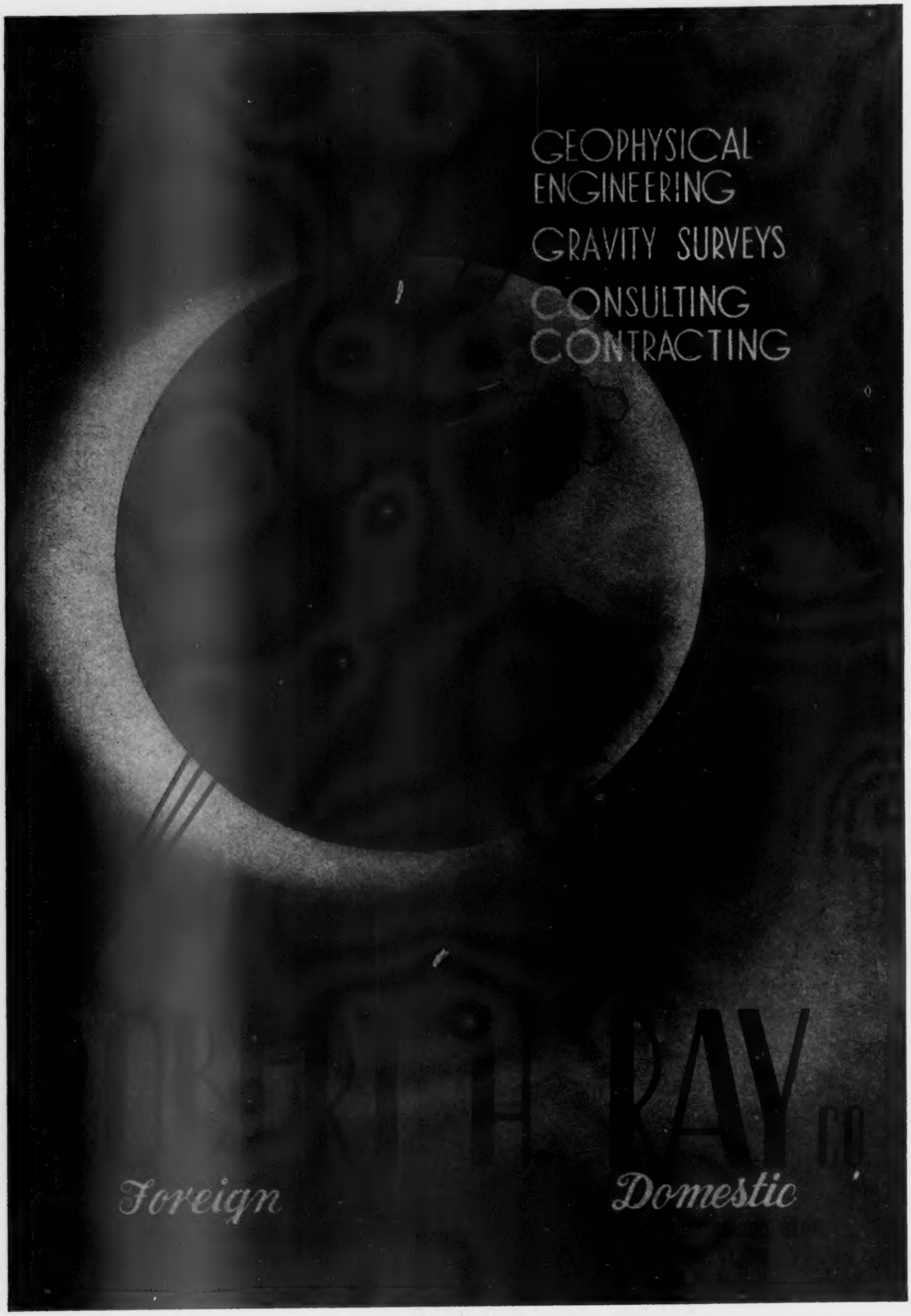

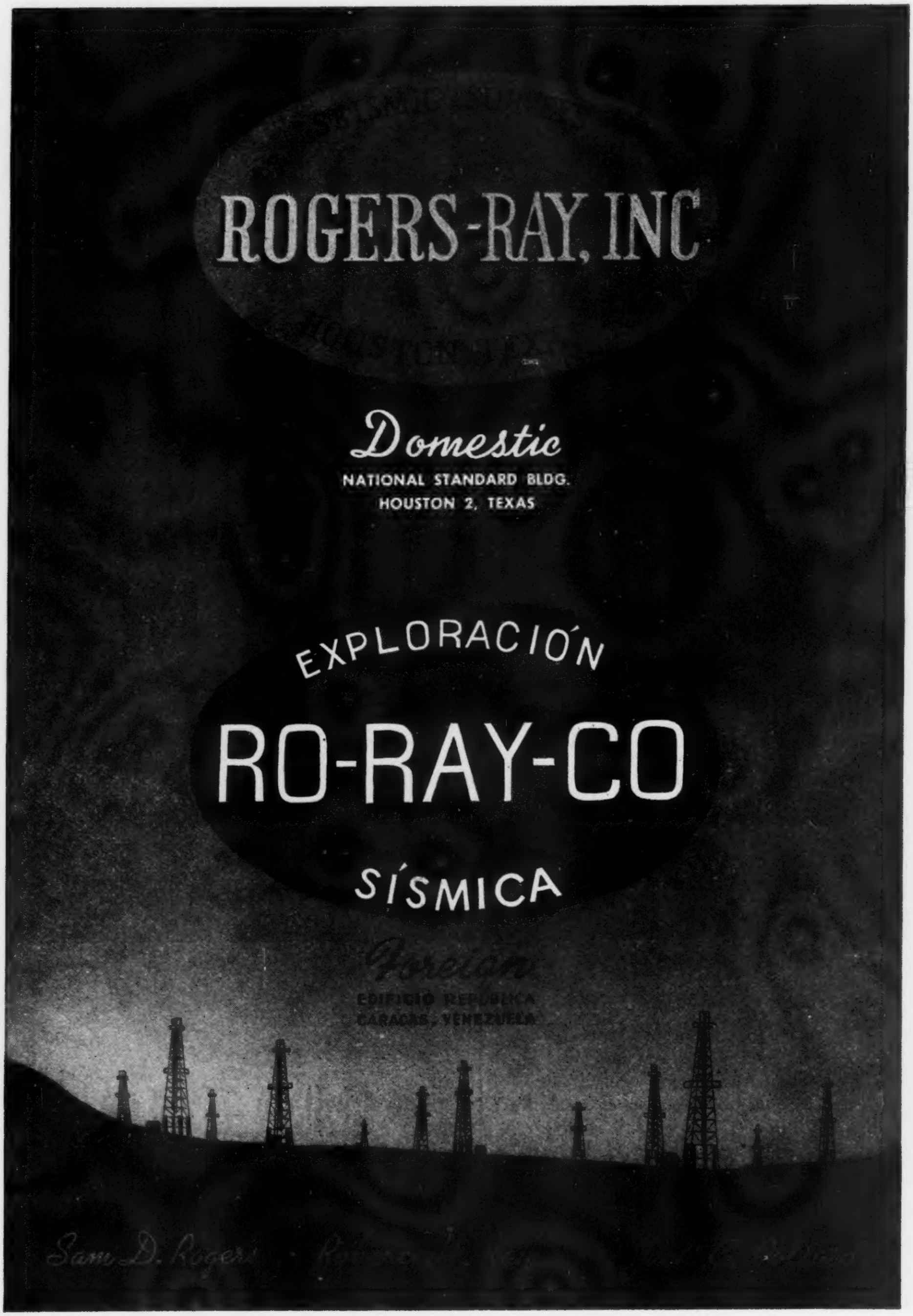

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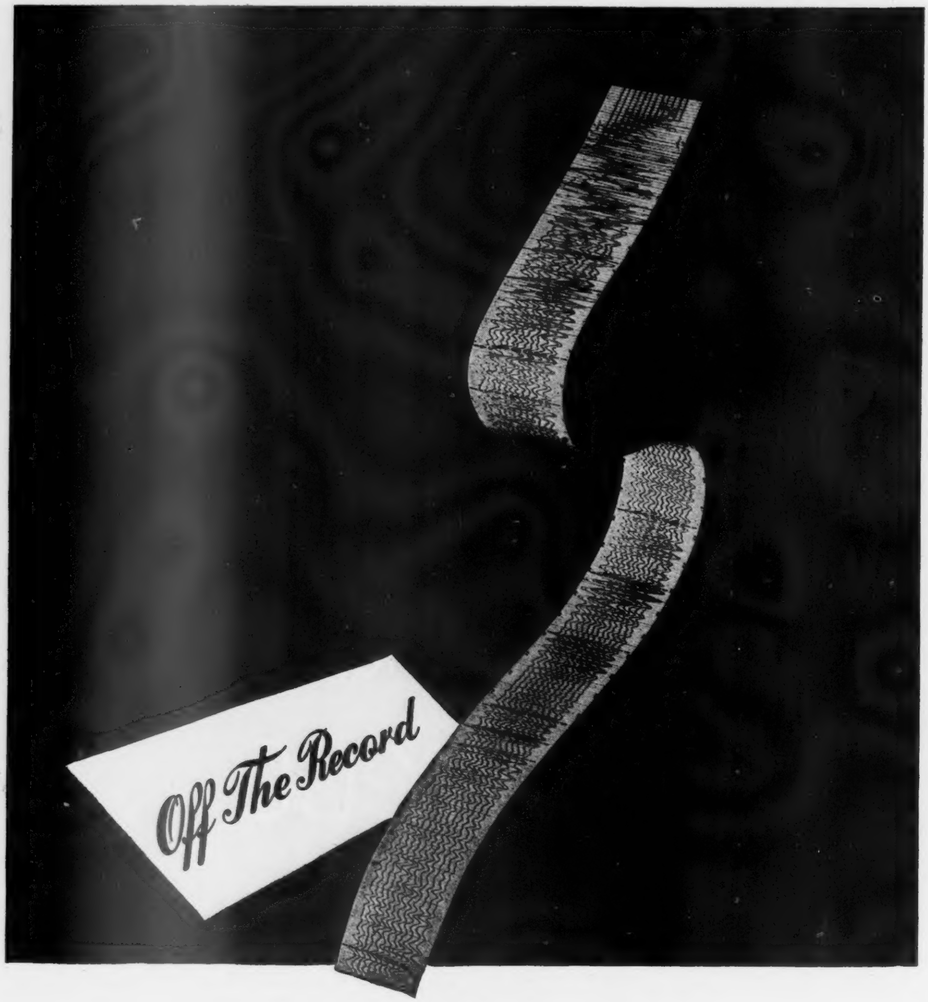
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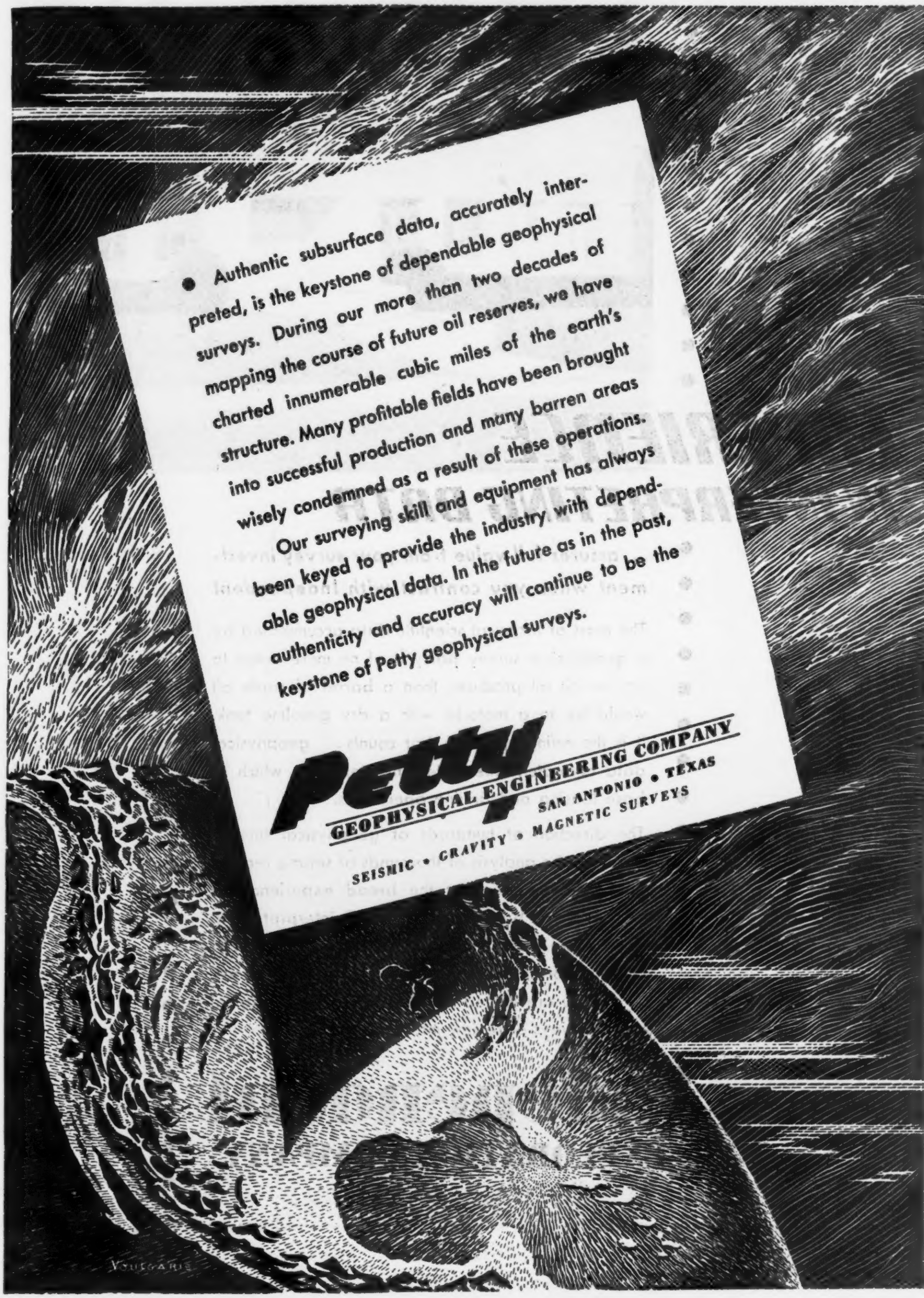

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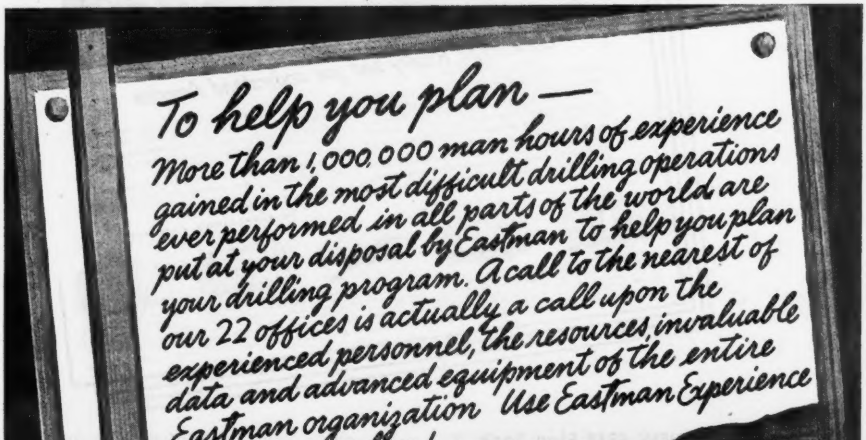

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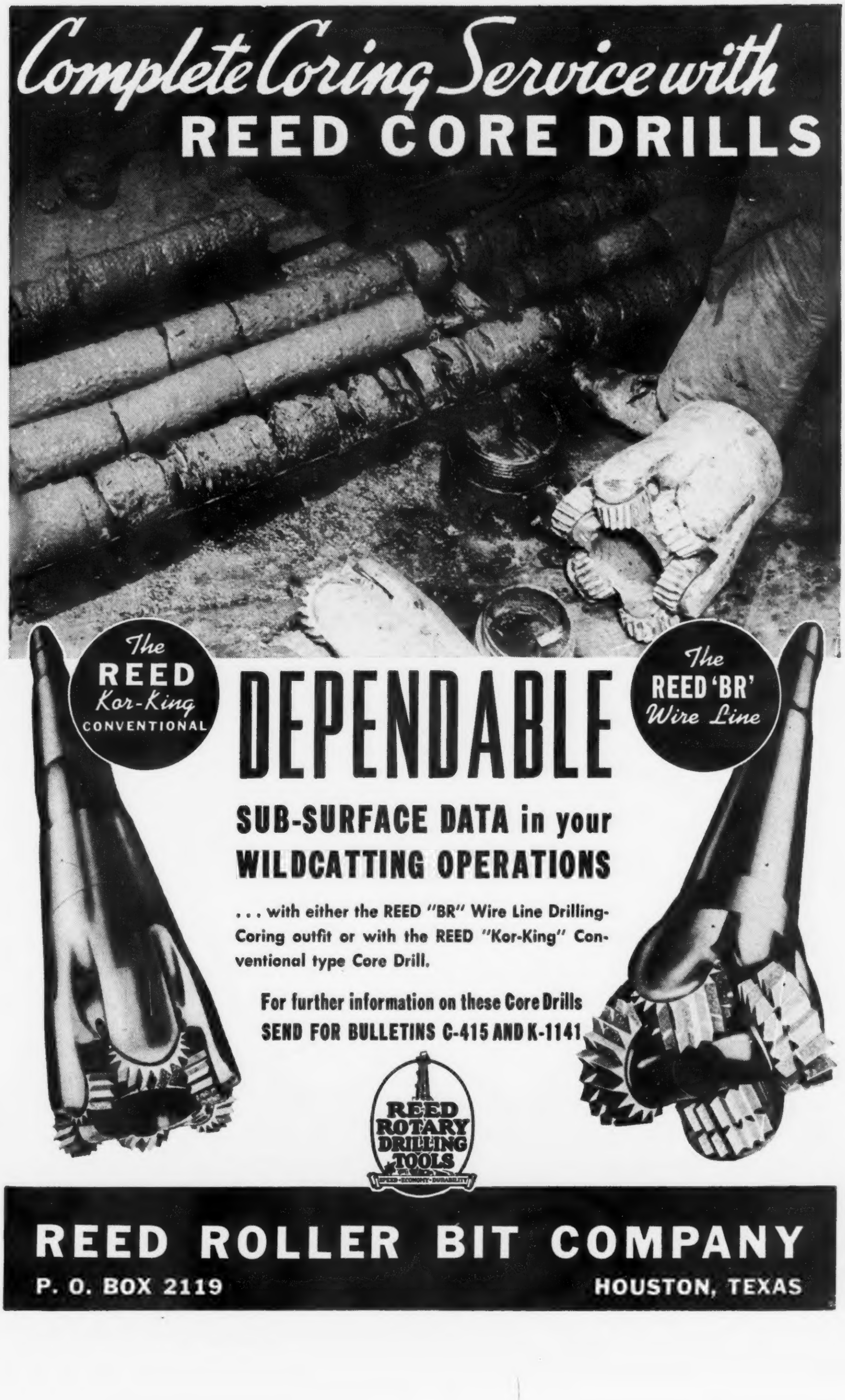
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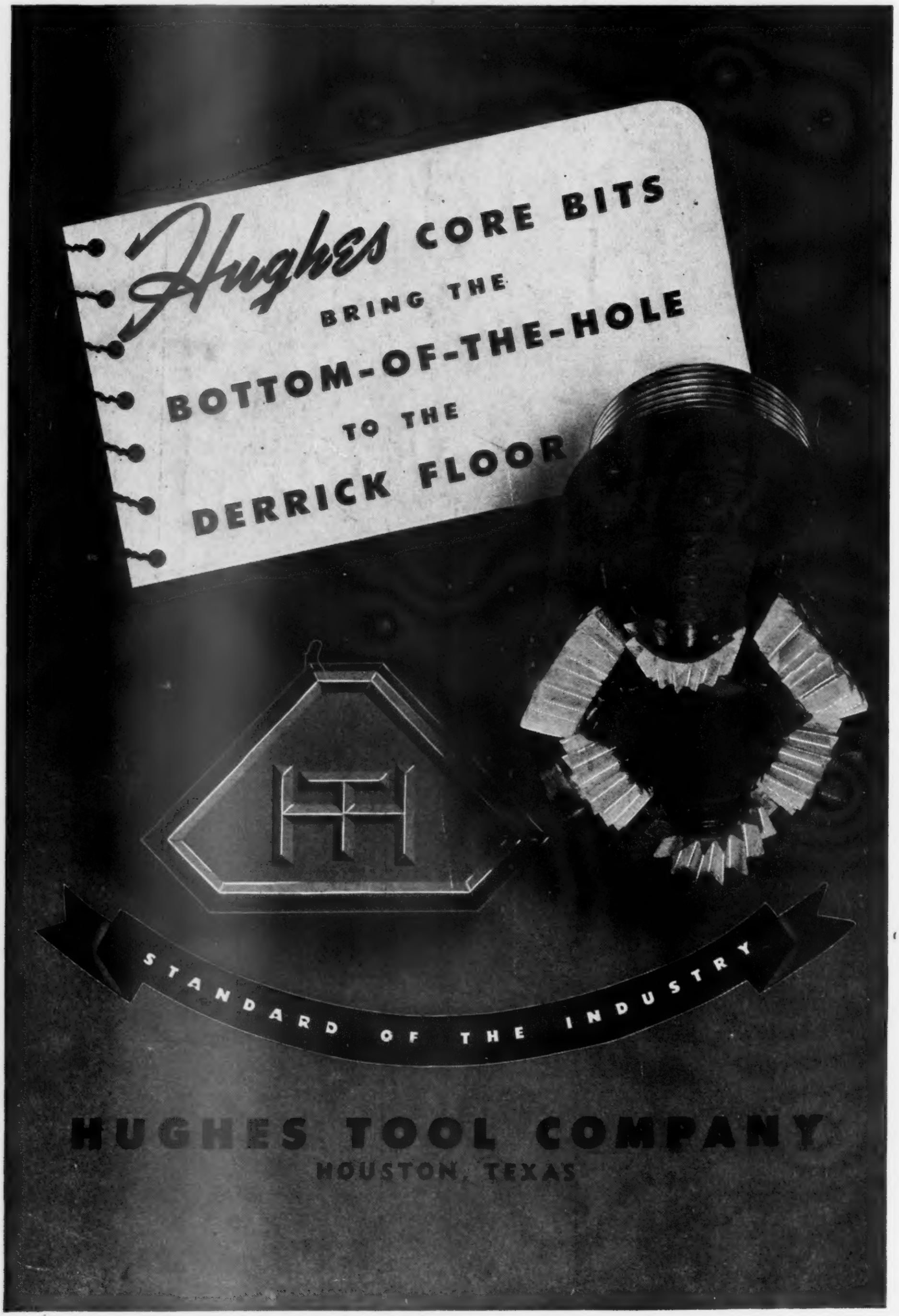
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